UNIVERSITY
OF MICHIGAN
JUL 25 1956
LIBRARY

SER. II. VOL. 18 NO. 8

TRANSACTIONS
OF
THE NEW YORK ACADEMY OF SCIENCES

June 1956

THE NEW YORK ACADEMY OF SCIENCES

(Founded in 1817)

COUNCIL, 1956

President
WALTER S. ROOT

President-Elect
ROSS F. NIGRELLI

Vice-Presidents
EDWARD J. KEMPF
BORIS PREGEL

Recording Secretary
CHARLES W. MUSKETT

Corresponding Secretary
FREDERICK C. NACHOD

Treasurer
RICHARD O. ROBLIN

Elected Councilors

1954-1956

JOHN M. CONVERSE
B. M. DUGGAR
RANDOLPH T. MAJOR
ABRAHAM SLAVIN

1955-1957

M. J. KOPAC
LLOYD C. MILLER
C. P. RHOADS
ELMER L. SEVERINGHAUS

1956-1958

DONALD B. REYES
CHARLES D. MARPLE
WARREN O. NELSON
FREDERICK Y. WISELOGLE

Finance Committee
HARDEN F. TAYLOR, *Chairman*
GORDON Y. BILLARD
ROBERT F. LIGHT

Executive Director
EUNICE THOMAS MINER

SECTION OF GEOLOGY AND MINERALOGY
M. HALL TAYLOR, *Chairman*
ANASTASIA VAN BURKALOW, *Secretary*

SECTION OF BIOLOGY
HILARY KOPROWSKI, *Chairman*
DANIEL LUDWIG, *Secretary*

DIVISION OF MYCOLOGY
JOHN B. ROUTIEN, *Chairman*
KARL MARAMOROSCH, *Secretary*

SECTION OF PSYCHOLOGY
ALBERTA S. GILINSKY, *Chairman*
RALPH F. HEFFERLINE, *Secretary*

SECTION OF ANTHROPOLOGY
JOHN L. LANDGRAF, *Chairman*
HAROLD C. CONKLIN, *Secretary*

SECTION OF PHYSICS AND CHEMISTRY
FRANK COLLINS, *Chairman*
ROBERT N. BOYD, *Secretary*

SECTION OF OCEANOGRAPHY AND METEOROLOGY
JEROME SPAR, *Chairman*
EDWIN L. FISHER, *Secretary*

SECTION OF MATHEMATICS AND ENGINEERING
NICHOLAS V. FEODOROFF, *Chairman*
S. B. LITTAUER, *Secretary*

Past Presidents
WILLIAM K. GREGORY
VICTOR K. LAMER
HORACE W. STUNKARD
M. L. CROSSLEY
HARDEN F. TAYLOR
JOHN TEEVAN
M. L. TAINTER

The Sections and the Division hold meetings regularly, one evening each month, during the academic year, October to May, inclusive.
Two-day conferences are also held at irregular intervals. All meetings are held at the building of The New York Academy of Sciences, 2 East Sixty-third Street, New York 21, New York.

SER. II. VOL. 18 *June 1956* NO. 8

TRANSACTIONS
OF
THE NEW YORK ACADEMY OF SCIENCES

CONTENTS

Specific Binding of Ions by Ion-Exchange Resins and Polyelectrolytes. *By* HARRY P. GREGOR 667
Marine Level-Bottom Communities of Recent Seas, Their Temperature Adaptation and Their "Balance" Between Predators and Food Animals. *By* GUNNAR THORSON 693
The Isolation of Viruses by a New and Rapid Method:
I. A New and Rapid Method for Isolating Viruses by Selective Fluorocarbon Deproteinization. *By* ALBERT E. GESSLER, CHARLES E. BENDER, AND MARTIN C. PARKINSON 701
II. Evaluation of a Fluorocarbon Technique for the Isolation of Plant Viruses. *By* CLARK A. PORTER 704
III. Animal Viruses and General Discussion. *By* ALBERT E. GESSLER .. 707
Atomic Power: Its Prospects and Realities. *By* THEODORE BAUMEISTER 718
River and Water-Supply Forecasting. *By* MAX A. KOHLER 732
The Nature of Law. *By* LEOPOLD J. POSPISIL 746
Conference Held 756
New Members 763

Copyright, 1956, by The New York Academy of Sciences

TRANSACTIONS of The New York Academy of Sciences, Series II, Volume 18, No. 8, June 1956.

Entered as second-class matter December 28, 1954, at the post office at New York, N. Y., under the act of August 24, 1912. This publication is distributed to members and is published monthly from November through June, inclusive, by The New York Academy of Sciences, 2 East 63rd Street, New York 21, N. Y.

Executive Director: EUNICE THOMAS MINER

SECTION OF PHYSICS AND CHEMISTRY

THE SPECIFIC BINDING OF IONS BY POLYELECTROLYTES: CORRELATIONS WITH BIOLOGICAL PHENOMENA*

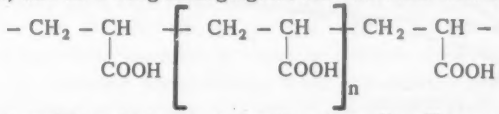
By Harry P. Gregor

Department of Chemistry, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Metallic cations are bound much more firmly to high-molecular-weight acids and bases than to the analogous monomeric compounds. Similarly, some anions are strongly bound to polybases. For example, the binding constant of copper (II) to polyacrylic acid is approximately 10^4 times that for the reaction between copper and the low-molecular-weight analogue, glutaric acid. Similarly, the binding of the iodide ion to a quaternary ammonium base is hardly measurable in dilute solution, but it is strong and pronounced with the polymeric analogue. These binding phenomena are not only important in themselves, but they appear to explain, in part, some of the binding properties of biological systems. The chemist, however, is still a long way from a duplication of many biological phenomena.

Some Experimental Procedures

Before considering some of the techniques for measuring the binding of ions, a brief review of some of the salient properties of polyelectrolytes is in order. Polyacrylic acid is a simple polyacid that has been studied extensively. This material is available from a number of sources** and is used for such purposes as a sizing agent for certain fabrics, as a soil conditioner, and as a coagulating agent. Its structural formula is:



When polyacrylic acid is titrated with a base its pH curve is quite different from that of the corresponding monomeric acid, propionic acid. FIGURE 1 shows a typical plot. The titration curve for a simple monomeric acid such as propionic acid is shown, as is another calculated curve for the polymeric acid where we consider only the so-called "statistical effect" of N. Bjerrum. When a polymeric acid dissociates at low degrees of neutralization there are as many ways for it to dissociate as there are dissociable groups. Once having dissociated, however, the number of ways for it to associate are considerably less. Because the rate of association is proportional to the number of ways to associate – and the same thing is true of the dissociation process – the

*This paper, illustrated with lantern slides, was presented at a meeting of the Section on May 1, 1956.

**For example, Acrysol, from Rohm and Haas Co., Philadelphia, Pa.

ionization constant of the polymer acid is much larger at low degrees of dissociation than that of propionic acid. On the other hand, at high degrees of neutralization there are a limited number of ways for the acid to dissociate but a very much larger number of ways for it to associate, once having dissociated. Accordingly, the ionization constant of the polymer acid at high degrees of neutralization is smaller. The average dissociation constant, that is, the dissociation constant at 50 per cent neutralization, must correspond to that for propionic acid.

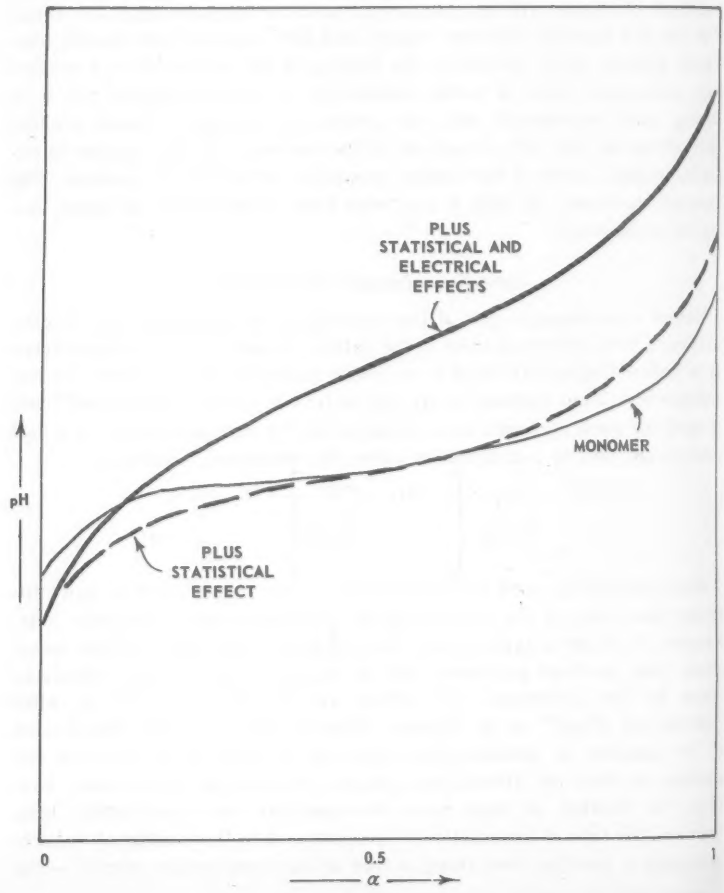


FIGURE 1.

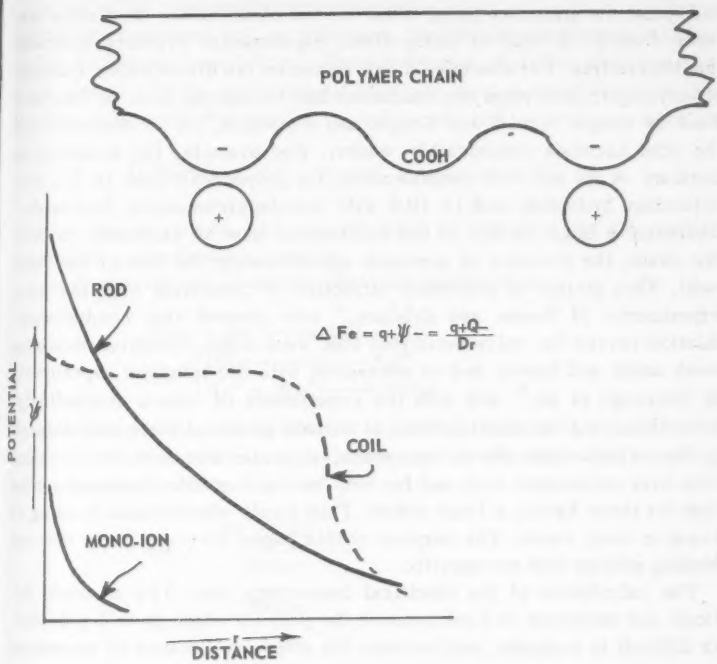


FIGURE 2.

Superimposed upon this statistical effect is a stronger effect, namely, that due to the electric charge on the chain. As the acid becomes neutralized the chain assumes a larger and larger negative charge. Accordingly, it becomes successively more difficult to remove protons, and the acid becomes successively weaker as α, the degree of neutralization, increases. It is a combination of these statistical and electrical effects that accounts for the titration curves that are measured.

The potential in the immediate vicinity of a charged or uncharged group on a polyelectrolyte chain is very much higher than it is for a low-molecular-weight acid or base. Whether one is dealing with a charged rod, as described by Fuoss *et al.*[1] and by Alfrey *et al.*,[2] a charged coil, as described by Kimball *et al.*,[3] or an assembly of charged plates, as described by Lazare *et al.*,[4] it is evident that the potential is quite high when compared to that calculated for simple ion systems, as shown in FIGURE 2. It is this very high chain potential that is primarily responsible for the effects observed.

It should be noted that the counterion in FIGURE 2, which would presumably be sodium ion if polyacrylic acid were neutralized with sodium

hydroxide, is drawn as being close to the chain rather than some distance from it. A body of fairly direct experimental evidence indicates that this is true. For example, if one measures the dissociation constant of polyacrylic acid when the counterion has increasing size, as has been done by Gregor *et al.*[5] and Gregor and Frederick,[6] it is observed that the acid becomes considerably weaker. For example, the dissociation constant at 90 per cent neutralization for polyacrylic acid is 9.1 with potassium hydroxide and is 10.9 with tetrabutylammonium hydroxide.[6] Obviously a large fraction of the counterions must be extremely close to the chain, the distance of approach approximating the sum of the ionic radii. This picture of coulombic attraction is consistent with the many experiments of Fuoss and Edelson,[7] who showed that conductance-dilution curves for polyelectrolytes that were salts resembled those for weak acids and bases, and is consistent with the transport experiments of Huizenga *et al.*,[8] and with the experiments of others. Accordingly, when there is a substantial chain or surface potential there will naturally be, unless other effects supervene, a greater attraction for divalent ions over monovalent ions and for ions having a smaller hydrated radius than for those having a large radius. This purely electrostatic binding is found in many cases. The purpose of this paper, however, is to discuss binding effects that are specific.

The calculation of the electrical free-energy term ΔFe is made difficult and uncertain at best because the polymer chain or coil potential is difficult to evaluate, and because the effective distance of separation of the charges and the dielectric constant of the intervening medium are both unknown. The usual practice is to use the bulk dielectric constant for the solvent (which is too large a value) and the sum of the ionic radii (which is too small) and arrive at a product that allows the calculated curve to fit the data.

Another property of polyelectrolytes deserves mention. If a neutral salt is added to a polyelectrolyte system it will migrate to the charged chain and reduce its potential by electrostatic shielding. A convenient and simple expression that describes the titration curves of simple and polymeric electrolytes in the range $0.3 < \alpha < 0.7$ is the Henderson-Hasselbalch equation,

$$pH = pKav + n \log (1 - \alpha) / \alpha$$

where *Kav* is the average ionization constant and *n* is the slope of the logarithmic plot. Both *Kav* and *n* are functions of the electrical free-energy term. Accordingly, if salt is added to the system and the electrical effects are diminished, *n* will decrease and *Kav* will increase, or the acid will become stronger and show smaller deviations from the behavior of the monomer. This effect is shown in FIGURE 3, where increasing amounts of potassium chloride have been added to 0.01 M of polyacrylic acid (based on mols of monomeric unit).

An excellent monograph that summarizes work in the field of the coordination complexes and, in particular, the chelate complexes has been written by Martell and Calvin.[9] Complexation or chelation phenomena involve essentially the displacement of a proton by a metallic cation. For example, the binding of calcium to oxalic acid may be written simply as,

$$(COOH)_2 + Ca^{++} \longrightarrow (COO)_2Ca + 2H^+$$

Here a ring is formed, and the compound is called a chelate complex rather than a coordination complex.

A more general way of writing chelation reactions is

$$HKe + Me^+ \longrightarrow MeKe + H^+$$

$$\begin{cases} HKe \longrightarrow H^+ + Ke^- \\ Ke^- + Me^+ \longrightarrow MeKe \end{cases}$$

This reaction is the sum of that for the dissociation of the chelate acid and for the formation of a metal chelate, and the corresponding equilibrium constants are written as

$$Ka = \frac{(H^+)\ (Ke^-)}{(HKe)}$$

$$K_f = \frac{(MeKe)}{(Me^+)\ (Ke^-)}$$

In most studies of complexation phenomena the experimental results are expressed in terms of the formation constant, K_f. The formation constant, however, does not include the dissociation constant for the acid, nor does it describe the displacement reaction. A more useful formulation from many points of view is the *B* constant[10], a product of the dissociation constant and the formation constant, or $B = KaK_f$. The *B* constant is a particularly useful formulation, and the expression is a somewhat more fundamental one in many reactions involving polyelectrolytes. Here the formation constant of the polymeric complex may be the same as for the monomeric complex but, since the polyacid is stronger, the over-all reaction is also stronger. Accordingly, K_f may be the same for the monomer as for the polymer, but the *B* constant would reflect the true experimental situation. Also, since the dissociation constant of a polymeric acid is affected strongly by the ionic strength of the solution, the *B* constant is more useful also because it reflects increases in the value of Ka with ionic strength and the corresponding decrease in K_f. As a result, the *B* constant is relatively insensitive to changes in ionic strength.

When neutral binding groups form complexes with metallic ions, as in the case of the ammonia complexes, the complexation reaction is es-

sentially the same as written before. For example, the reaction between an amine and a metal ion is

$$n\mathrm{RNH_3^+} + \mathrm{Me^+} \longrightarrow \mathrm{Me(RNH_2)_n^+} + n\mathrm{H^+}$$

and corresponds to the displacement of the acid proton by the metallic cation.

The experimental techniques used to calculate formation constants and the displacement constant are summarized in Martell and Calvin.[9] The most simple procedure involves a pH titration of the chelate acid followed by the same titration of the chelate acid in the presence of different amounts of a metallic cation. FIGURE 4 shows a typical curve where the decrease in the pH at a given value of α upon the addition of

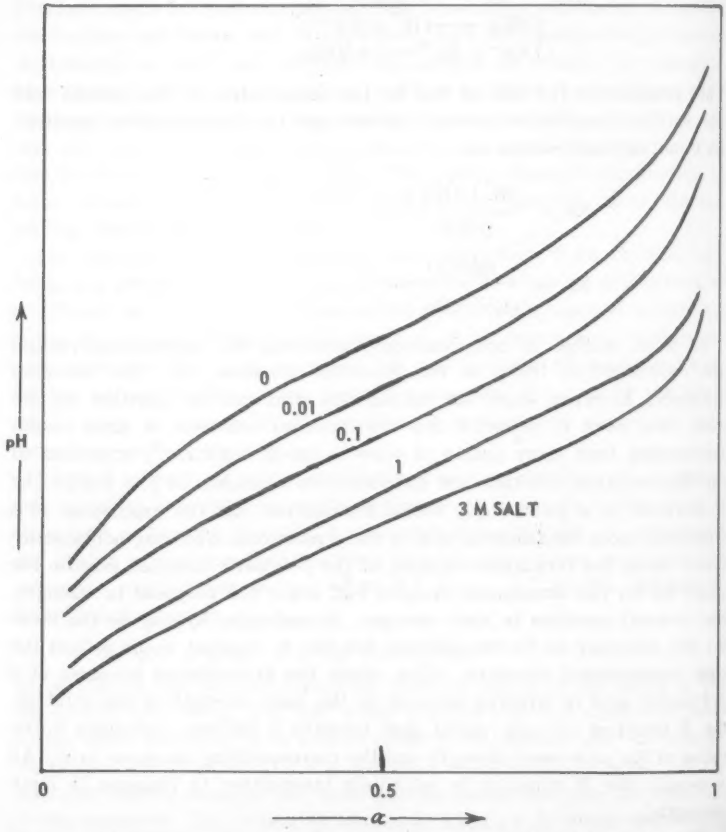


FIGURE 3.

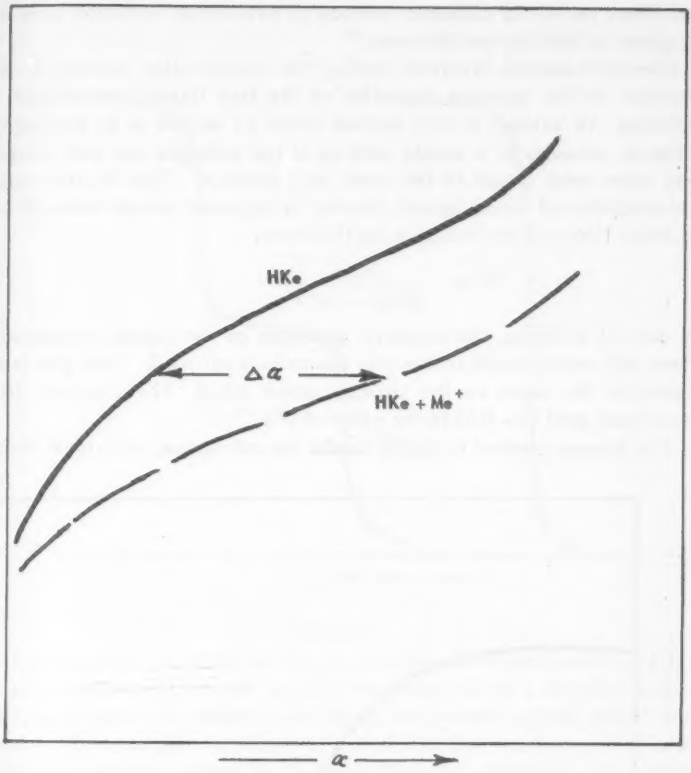


FIGURE 4.

metal is a direct measure of the mols of hydrogen ion displaced by the metallic cation. The horizontal displacement $\Delta\alpha$ is a direct function of the formation constant at that pH level.

The use of the potentiometric method is complicated by the fact that complexation usually does not take place between a single ligand (group that is attached to a coordination position of a metallic cation) and a metallic cation but, rather, proceeds stepwise as shown below:

$$Me^+ + Ke^- \longrightarrow MeKe$$
$$MeKe + Ke^- \longrightarrow MeKe_2^-$$
$$MeKe_2^- + Ke^- \longrightarrow MeKe_3^=, \text{ etc.}$$

Since a rigorous solution of this problem would involve the simultaneous solution of a number of equations, the problem is usually not attacked in this manner. Rather, the ingenious method of J. Bjerrum is used. An

excellent review of different methods of evaluating formation constants is given by Sullivan and Hindman.[11]

Bjerrum's method involves plotting the complexation number, $\bar{n}$, as a function of the negative logarithm of the free ligand concentration in solution. An analogy to this method would be arrived at by treating the titration behavior of a simple acid as if the hydrogen ion were a ligand and were being bound to the weak acid anion A^-. Then $\bar{n}$, the average concentration of bound ligands divided by the total concentration of ions to which they may be bound, is for this case,

$$\bar{n} = \frac{(HA)}{(HA) + (A^-)}$$

A plot of $\bar{n}$ versus the negative logarithm of the ligand concentration (here pH) would result in the plot shown in FIGURE 5. This plot is essentially the same as the titration curve itself. The mid-point for a monobasic acid ($\bar{n} = 0.5$) is the value of pKa.

The Bjerrum method is highly useful for calculating individual ioniza-

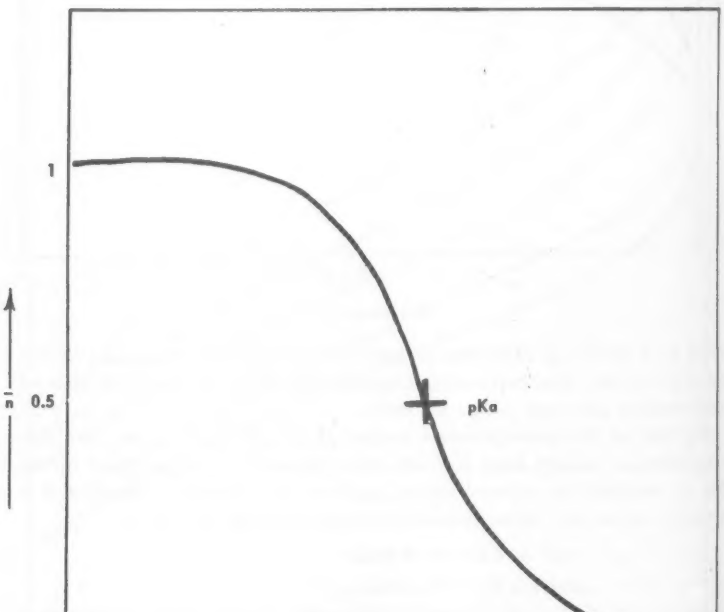


FIGURE 5.

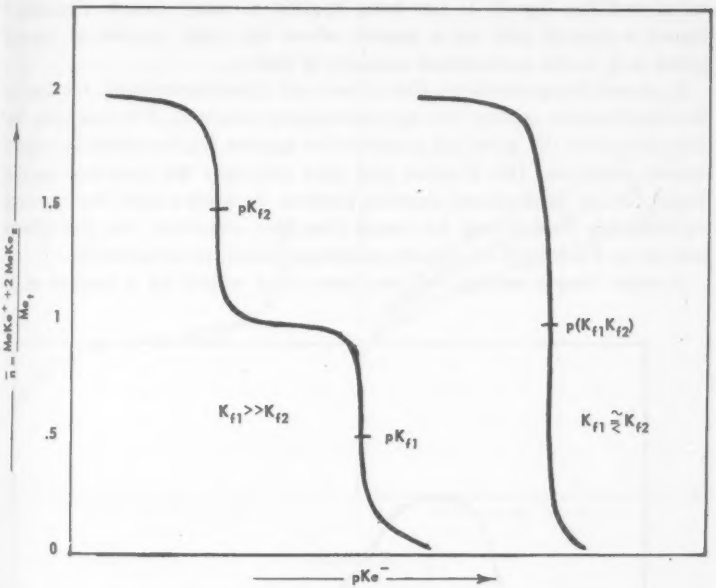


FIGURE 6.

tion constants for polybasic acids, for complex acids and bases, and for chelate complexes. Consider a simple reaction where a metallic cation (Me^{++}) is bound to a chelate anion (Ke^{-}) in 2 steps to form $MeKe^{+}$ and $MeKe_2$. A Bjerrum plot is shown in FIGURE 6. The maximum value of $\bar{n}$ is the coordination number N. If the 2 formation constants are widely separated, one obtains 2 distinct steps, and the mid-points at $\bar{n} = 0.5$ and $\bar{n} = 1.5$ give values of the 2 formation constants. If the 2 formation constants are not widely separated, however, a single curve results. In certain cases chelates are formed where the second formation reaction will occur more readily than the first, that is, once the first step has occurred the second step occurs more readily. Procedures for the evaluation of the so-called spreading factor, which is related to the ratio of K_{f2}/K_{f1}, are described in the literature.

A useful procedure for the evaluation of the predominant chelate species formed is the method of Job, where solutions of varying ratios of the total ligand (Ke_t) and metallic ion (Me_t) concentrations are prepared, keeping the total concentration constant. The optical density of these solutions is measured at some wavelength corresponding to maximum absorption of the complex, and a maximum is found at the point corresponding to the composition of the predominant species present. This method requires that the complex absorb strongly compared to the

metal and the ligand. It has been applied in many cases. FIGURE 7 shows a typical plot for a system where the total number of ligands bound is 2, or the predominant complex is $MeKe_2$.

It should be pointed out that these and other techniques for finding the coordination number are not necessarily absolute. For example, the Job plot gives the principal coordination number for the existing experimental situation. The Bjerrum plot also indicates the maximum number bound for the predominant species present. In some cases the maximum coordination number may be larger than that observed, but the effects may be so weak as to be almost indistinguishable experimentally.

Another simple method that has been used widely by a number of in-

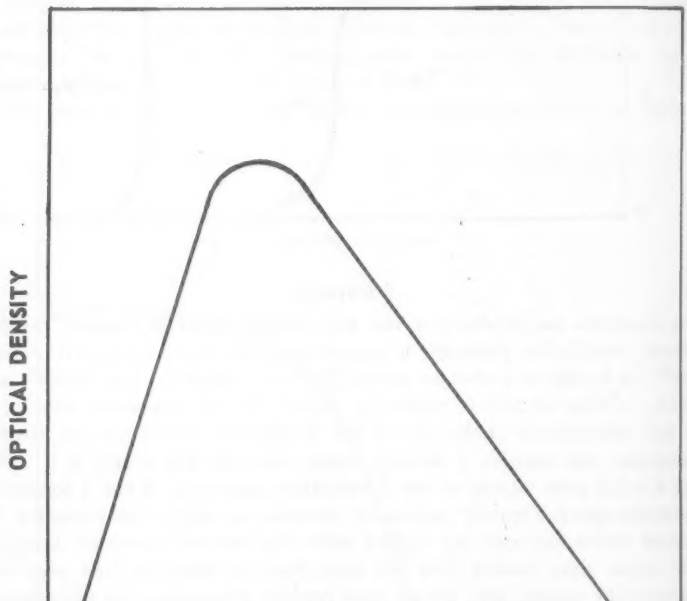


FIGURE 7.

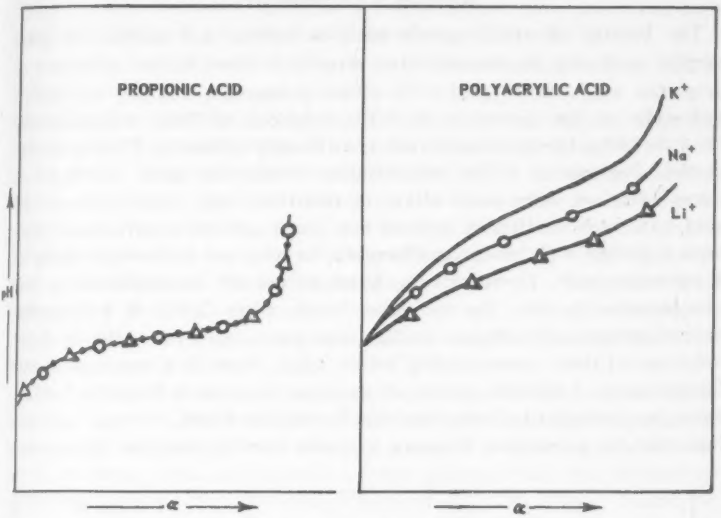


FIGURE 8.

vestigators involves equilibrium dialysis. Here the polyelectrolyte is contained in a membrane bag and is equilibrated with varying concentrations of metallic cation. The metallic cation concentration in the external solution is determined directly, and the amount bound by the polyelectrolyte can be calculated by difference.

Another experimental technique that allows a direct determination of the binding of an ion by a polyelectrolyte involves preparing the polymer in the form of an insolubilized phase, either as an ion-exchange resin or an ion-exchange membrane. Here the exchange phase is equilibrated with solutions of varying concentrations and pH levels, the phases are separated, and the uptake of ion is determined directly by elution. While this technique is simple and direct, formation constants calculated by this method can be compared directly with the other techniques only when a high concentration of neutral salt is present, because the familiar Donnan effects act to concentrate exchange ions in the resin phase, excluding those of opposite sign. For example, a polycarboxylicacid resin concentrates cations in the resin phase and excludes anions. Accordingly, if the resin were equilibrated with a dilute solution of a metallic cation, one would calculate a formation constant that was too large, because the concentration of cations in the resin phase was higher than in the ambient solution. The addition of a large excess of "neutral salt" swamps the Donnan equilibrium and makes a direct comparison possible.[12]

Results of Experiments

The binding of alkali metals such as lithium and sodium by polyacrylic acid can be demonstrated directly.[6] When dilute solutions of propionic acid are titrated with either potassium, sodium, or lithium hydroxide in the presence of 0.2M solutions of their corresponding chloride salts, the titration curves are virtually identical. This is as expected, because at 0.2M concentration levels the mean activities of these salts are very much alike. In relatively high concentrations an acid salt such as lithium acetate has lower activity coefficients than does a sodium salt, whose coefficients, in turn, are lower than those of a potassium salt. These effects, however, are not demonstrable at low concentration levels. On the other hand, when 0.001 M polyacrylic acid is titrated with lithium, sodium, and potassium hydroxides in 0.2M solutions of their corresponding halide salts, there is a pronounced difference in the 3 titration curves, as shown in FIGURE 8. Here the lithium curve is substantially lower than that for sodium which, in turn, is lower than that for potassium. FIGURE 8 shows directly that the lithium ion

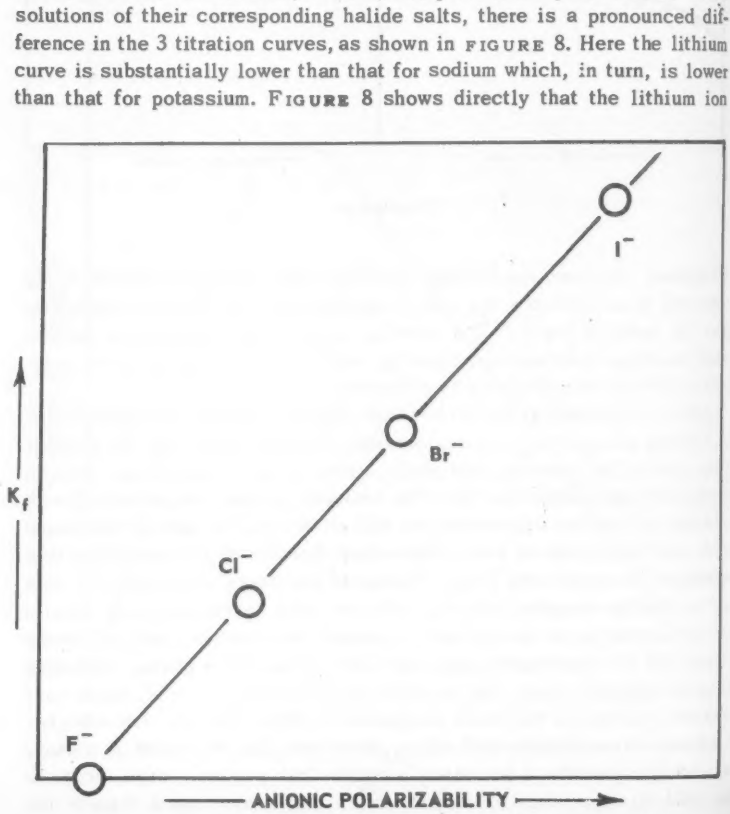


FIGURE 9.

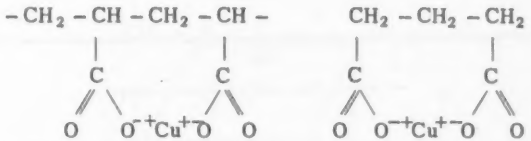
preferentially displaces hydrogen ion from polyacrylic acid when compared to sodium and potassium and, therefore, is "bound."

An even more direct demonstration of this binding effect can be achieved by cross-linking polyacrylic or polymethacrylic acid and measuring the selective uptake that occurs in the order lithium > sodium > potassium. These effects have been shown by Gregor *et al.*[13]

The exact reasons for the binding of lithium and sodium by carboxyl groups are obscure. Some authorities ascribe the binding to the entrance of the negative carboxylic group into the hydration sphere of the cation. Others believe it is caused by hydrogen bonding or "localized hydrolysis." Regardless of the exact mechanism involved, FIGURE 8 does demonstrate the much stronger effects observed with polyelectrolytes than with their monomeric analogues. These effects differ in intensity, but probably not in kind.

The binding of anions by polymeric bases is, similarly, considerably greater than that observed for their low-molecular-weight analogues. Formation constants for the binding of anions to a quaternary-ammonium-anion exchange resin containing exchange groups of the benzyltrimethylammonium type were calculated by Gregor *et al.*[14] These were: iodate, 0; fluoride, 0; chloride, 1.7; bromide, 3.3; iodide, 33; thiocyanate, 50; toluenesulfonate, 60; and trichloracetate, 70. This binding of anions by polybases is related to the deformability or ionic polarizability of the anion. FIGURE 9 shows a plot of the formation constant as a function of the ionic polarizability. Comparisons should be made only for ions in homologous series, because polarizability effects would be different for anions of different structures and types.

The binding of divalent metals by polyacrylic acid and by its monomeric analogue, glutaric acid, has been studied in some detail by Gregor, Luttinger, and Loebl.[10,12] Here the predominant chelate species is the dicarboxylate complex, probably an 8-membered ring formed with adjacent carboxylate groups. The ring structures for the monomer and polymer are:



Copper polyacrylate Copper glutarate

Comparable titrations of 0.01 M polyacrylic acid and 0.01 N glutaric acid in the absence and presence (2 M sodium nitrate) of neutral salt and 0.01 M copper (II) nitrate are shown in FIGURE 10, and they demonstrate the considerable differences between the 2 analogous metal chelates. The decrease in pH is very pronounced with the polyacid

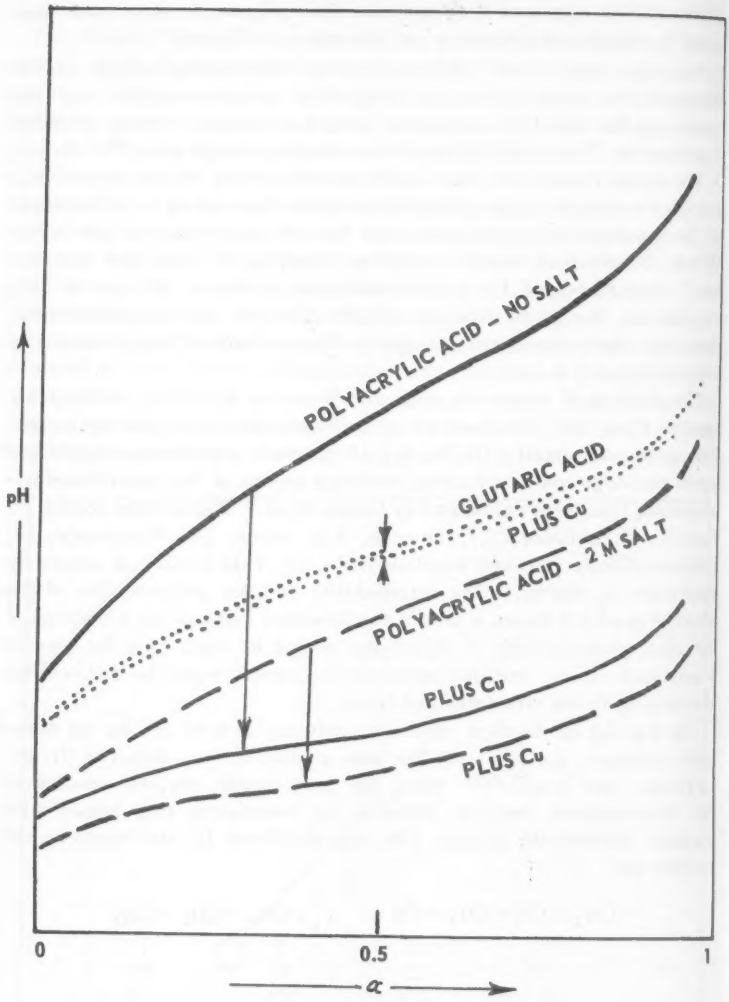


FIGURE 10.

and copper in the absence of salt, and is still pronounced in 2 M sodium nitrate. With glutaric acid, the comparable titrations yield differences that are difficult to measure. TABLE 1 summarizes some of data obtained, showing that the formation constant of the polychelate is greater by 3 orders of magnitude in the absence of neutral salt than it is in 2 M sodium nitrate. This considerable effect reflects the sharp

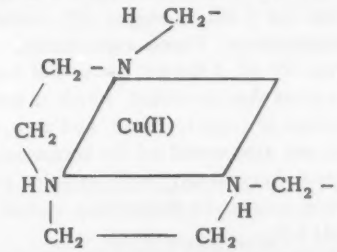
increase in the dissociation constant of the acid with increasing salt concentration. Accordingly, the *B* constant for the over-all displacement reaction is considerably less dependent upon ionic strength, varying only by a factor of 3.

The formation constant for copper glutarate is fairly independent of ionic strength, but it is from 3 to 6 orders of magnitude smaller than that for copper polyacrylate. A part of this considerably enhanced binding may be due to the somewhat lower degrees of freedom possessed by the carboxylate groups in polyacrylic acid as compared to glutaric acid, because the former are side groups of a chain, and the predominant effect is apparently the chain potential.

The ratio of b_1/b_2 is 0.3 for polyacrylic acid in 2 M salt and is 7.0 for glutaric acid measured under the same conditions. Thus b_1 is smaller than b_2, which is typical of most polychelate reactions. Once the metal is attached to a ligand on the polymer chain, the second ligand attaches with greater facility. This is not observed to be the case with glutaric acid, where the 2 formation constants are separated by approximately 1 order of magnitude.

The total number of carboxylate groups joined to copper with polyacrylic acid is predominantly 2, although the titration curves suggest evidence for a complexation number of 4. Obviously the preferred complexation number would be N = 2 from the point of electrical neutrality. Measurements on the viscosity of copper polyacrylate solutions also indicate that the coordination number is 2, probably reflecting binding by adjacent carboxylate groups, as measured by Gregor and Bownes.[15] Job plots also indicate that N = 2 is the predominant binding, although the gelling of polyacrylic acid with copper at higher pH levels suggests that N = 4 also applies.

The binding of copper and other metals by polybases has been studied by Bastian and Gregor.[16] Here apparently 3 nitrogens are bound per mol of copper (II). The polychelate of copper (II) and polyethyleneimine is



This conclusion was drawn from the results of titration studies, and also from a Job analysis, as shown in FIGURE 11. The reasons why the coordination number is not 4 are not clear. The binding of lower-molecular-weight polyimins – tetraethylenepentamine, for example – has been

TABLE 1

COMPLEXATION OF COPPER (II) WITH CARBOXYLIC ACIDS

Acid	$NaNO_3$ M	B_2	K_2	b_1/b_2
Glutaric	0	1.7×10^{-6}	7.2×10^{3}	13
Polyacrylic	0	4.2×10^{-3}	9.1×10^{9}	2
Polyacrylic	0.2	4.6×10^{-3}	3.0×10^{7}	0.76
Polyacrylic	2	11×10^{-3}	9.6×10^{6}	0.33

studied by Jonassen and Meibohm [17] and others, who also report a coordination number of 3.

Approximate values of the formation constant K_3 for copper (II) with various amines are as follows: ammonia, 10^{15}; ethylenediamine, 10^{18}; tetraethylenepentamine, 10^{20}; and polyethyleneimin, 10^{24}. In order to make a more significant comparison, values for the binding of the 3 groups have been compiled. Ethylenediamine is bound 3 orders of magnitude more strongly than is ammonia, reflecting increased stability due to the formation of chelate rings. Again, tetraethylenepentamine is bound 2 orders of magnitude more strongly than ethylenediamine, while polyethyleneimin binds copper even more strongly, approximately 4 orders of magnitude more strongly than does its lower-molecular-weight analogue, tetraethylenepentamine. Further, the binding of copper by polyethyleneimin also proceeds in essentially a single step, that is, $k_3 > k_2 > k_1$.

Differences in the binding power of polyelectrolytes, or monomeric chelates for that matter, with different metals are observed from their behavior at different pH levels. For example, metallic ions that compete relatively favorably with the hydrogen ion are bound at low pH levels, while those that compete less favorably, that is, are bound weakly, are complexed only at high pH levels. FIGURE 12 shows some typical complexation titration curves for 0.001 M copper (II), nickel (II), and zinc (II) with 0.01 M polyethyleneimin. These experiments, performed at the same concentration levels for all 3 metals, show that copper is bound at considerably lower pH values than is nickel, which is bound more strongly than is zinc. In a mixture of copper, nickel, and zinc, copper would be bound at a low pH level and zinc would not be bound until a much higher pH level had been reached. Accordingly, with an anion exchange resin of the polyethyleneimin type, copper is selectively sorbed at pH 3, nickel at pH 4.5, and zinc at pH 5.5.

The binding of transition metals by polyamines is apparently stronger than with polycarboxylic acids, if one is to place reliance on the calculated formation constants. That these values have semiquantitative validity can be seen by making a direct comparison between the 2

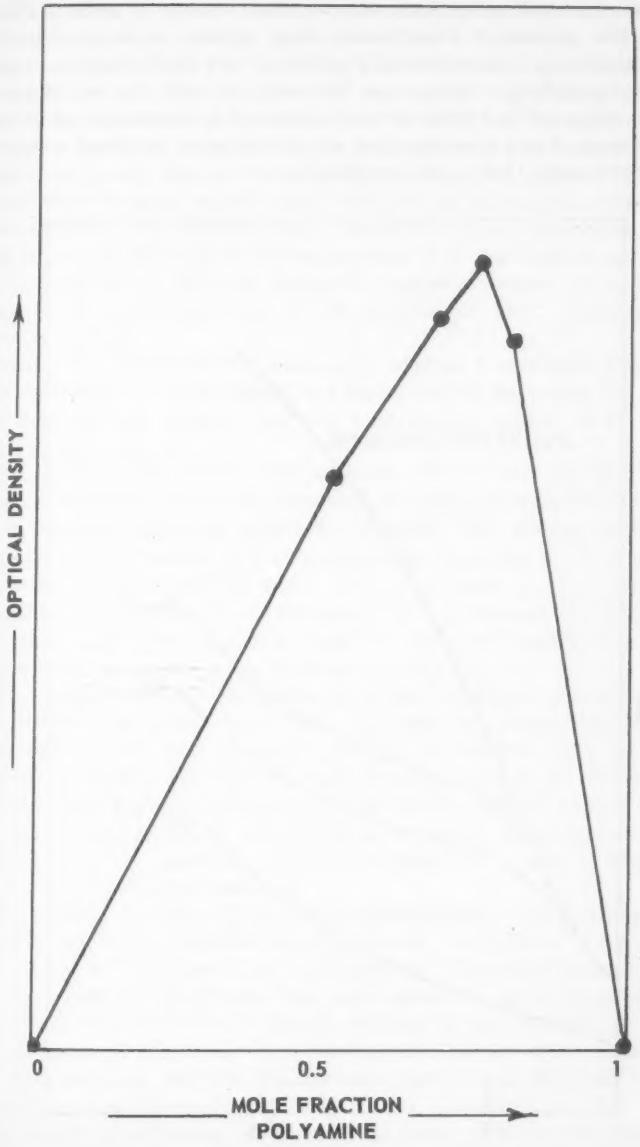


FIGURE 11.

polymers by equilibrating each with the same solution of metal and comparing the amounts of bound metal. When soluble polyelectrolytes are being compared, a semipermeable membrane will serve. With the cross-linked ion-exchange resins, one has only to shake to equilibrium a system composed of 2 kinds of resin separated by a screen or cloth bag. Experiments of this type show that polyethyleneimin is indeed a stronger complexing agent than is polyacrylic acid.

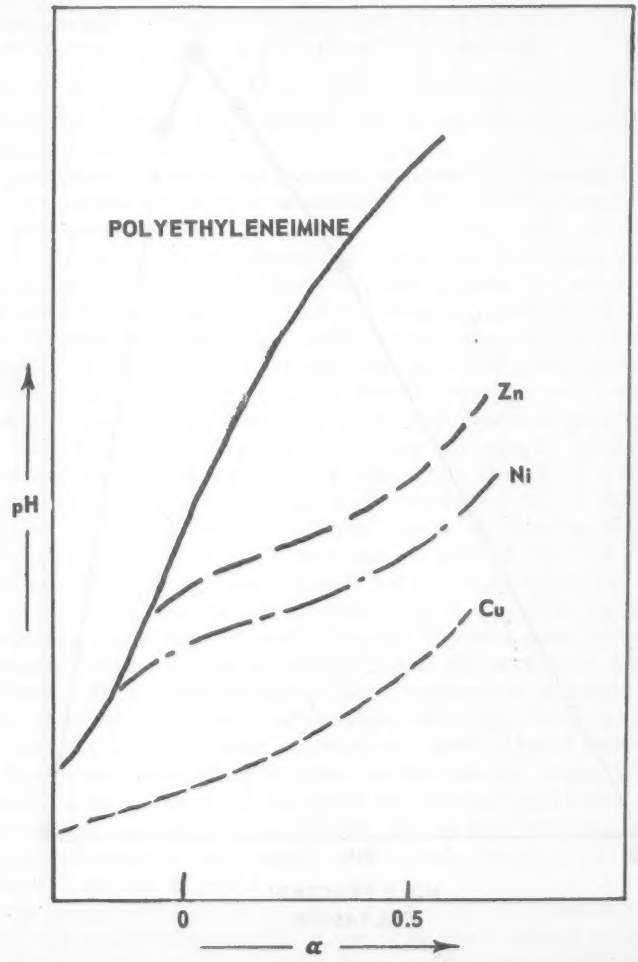


FIGURE 12.

The binding of metallic cations by a polymeric amine that is of considerable interest, namely, polyvinylimidazole, has been studied by Gregor and Gold.[18] Copper is strongly bound by polyvinylimidazole, as shown in FIGURE 13. Also shown in FIGURE 13 is a binding curve for copper (II) by imidazole, as studied by Edsall *et al.*[19] Here it is seen that the formation constant of the polychelate is several orders of magnitude greater than for the copper imidazole. The value of k_1 is approximately the same in both cases. With the polyelectrolyte, however, 3 more groups on the polymer chain immediately attach themselves to the copper ion. In the case of imidazole there is a considerable spreading factor between the different formation constants. Indeed, it is the extremely low spreading factor of the polychelate which makes for its stronger binding.

There is a legitimate question as to whether 4 imidazole groups in polyvinylimidazole could indeed find places around the copper ion, since the data strongly suggest that the complexation number is 4. A Job analysis also gave $N = 4$.

The neutral salt effect with polybases differs from its effect with polyacid chelates. As stated previously, the average ionization constant of a polyacid increases with ionic strength. The average ionization constant of a polybase must correspondingly increase, or its acid dissociation constant must decrease with an increase in ionic strength. Therefore, the addition of salt decreases the acid strength of a polybase, and this result must, therefore, make for stronger complexation rather than weaker complexation, as shown in FIGURE 14.

The preparation and properties of a new synthetic polyampholyte, poly-N-ethyleneglycine, have been reported by Gregor, Gold, and Hoeschele,[20] and this compound's binding of metallic ions has been studied by Gregor and Gold.[21] Polyethyleneglycine is an interesting polyampholyte because its low equivalent weight makes it soluble at all pH levels and prevents it from being salted out by even high salt concentrations at its isoelectric point. Accordingly, it is easy to study as regards its complexation behavior.

The binding of copper (II) by polyethyleneglycine is quite strong compared to that by its analogue, dimethylglycine. In addition, a complexation number $N = 6$ is found from a Job analysis. The complexation number of copper with dimethylglycine has been reported to be 4. Complexation numbers of 6 for copper are virtually unknown in the literature. J. Bjerrum has reported indications for a complexation number of $N = 6$ for copper and ammonia, but the effects were quite weak. With the polyelectrolyte polyethyleneglycine the effect is pronounced.

A number of additional complexing polymers, either in the form of soluble polyelectrolytes or in the form of cross-linked polyelectrolytes or ion-exchange resins, have been reported in the chemical literature. In some cases complexing or precipitating agents were prepared in the

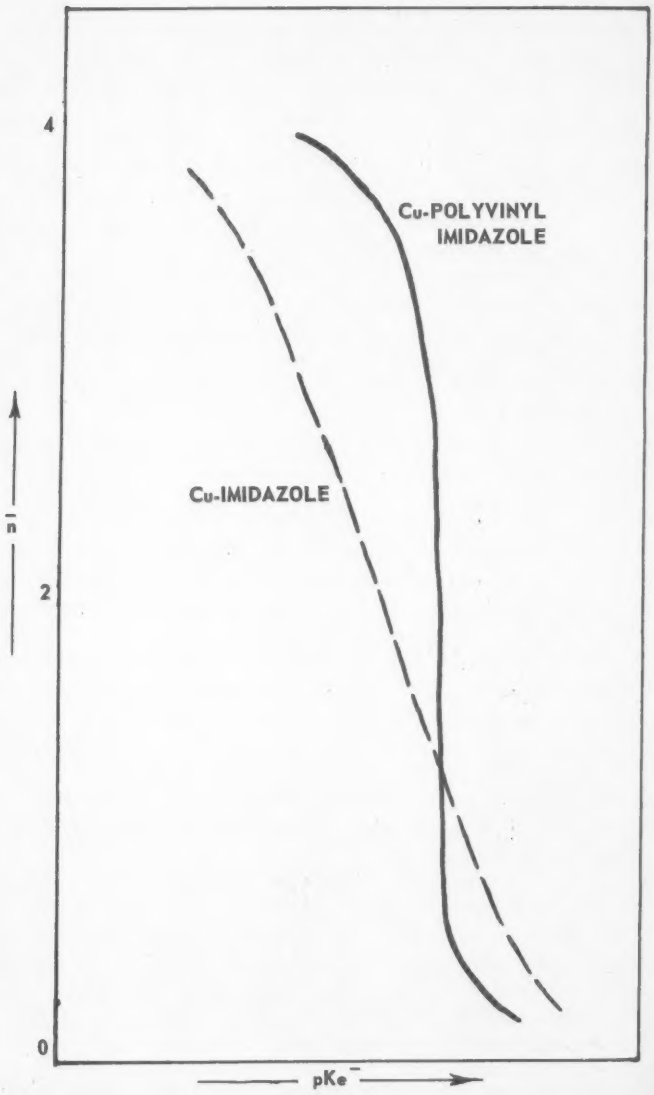


FIGURE 13.

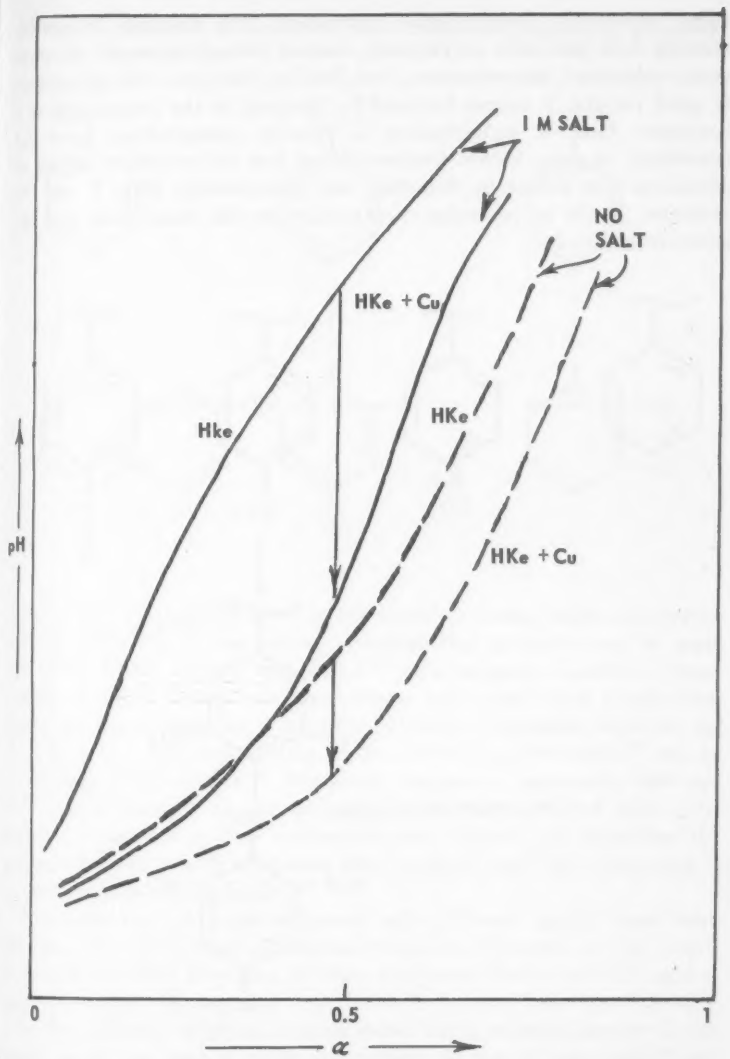
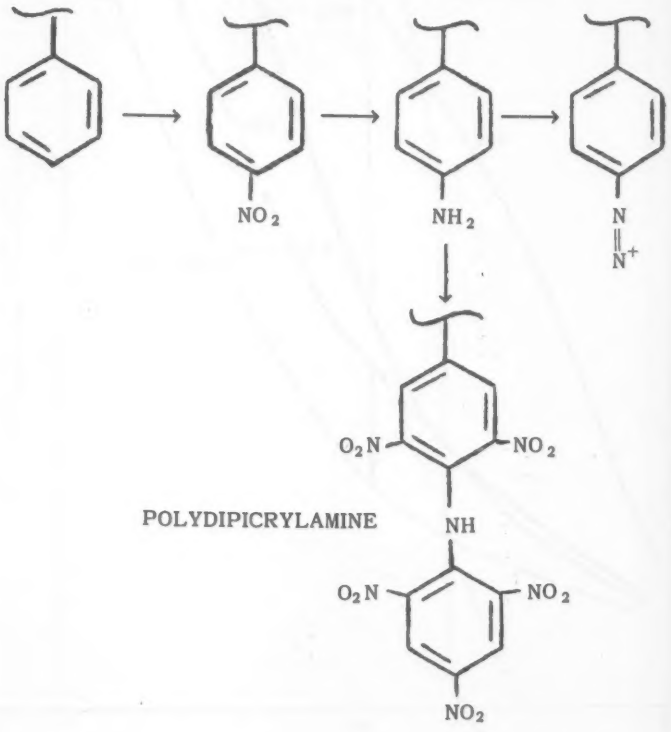


FIGURE 14.

form of resins or polyelectrolytes. In others, the binding seems to be principally the result of chain potential effects.

The original work of Skogseid[22] has demonstrated that polymers and resins can be prepared by the treatment of polymeric starting materials,

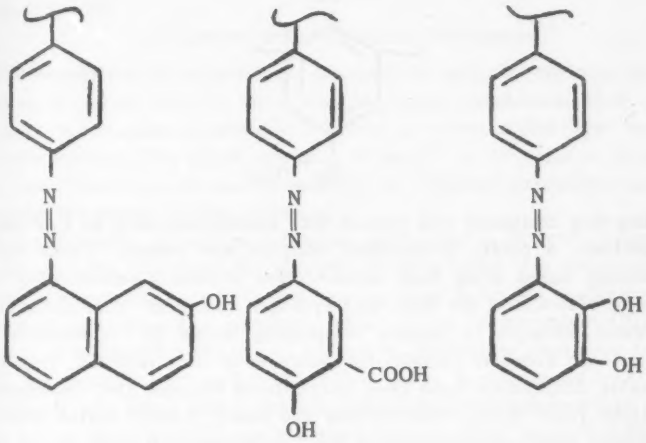
using essentially conventional techniques. For example, Skogseid, starting with insoluble polystyrene, carried through a series of nitrations, reductions, diazotizations, and coupling reactions with surprisingly good results. A course followed by Skogseid in the preparation of a polymeric form of dipicrylamine, a specific precipitating agent for potassium, is given below. Skogseid found that the selective uptake of potassium over sodium by this resin was approximately 10 to 1, and the selective uptake by potassium over calcium by the same resin was approximately 3 to 1.



POLYDIPICRYLAMINE

These binding results do not appear to conform with those observed when dipicrylamine is used as a specific precipitant for potassium. The binding reaction with the polyelectrolyte or resin does not appear to be as specific as in the case of the monomeric material, probably because the contribution of the lattice energy of potassium dipicrylaminate is missing with the polymeric complex.

Skogseid prepared a number of other complexing agents in polymeric form, as shown below.

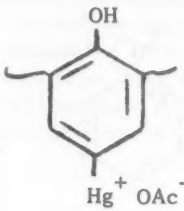


Since the diazonium salt of either linear or cross-linked polystyrene can be prepared, a large series of complexing polymers may be made available. Chen, Spoerri, and Gregor[23] have prepared a number of compounds of these types based upon linear and cross-linked polystyrene. Using similar techniques, a specific polymeric complexing agent of the thiol type has been prepared by Gregor, Dolar, and Hoeschele[24] and by Overberger and Lebovits.[25] Overberger prepared a monomeric form and then polymerized it to poly-p-thiolstyrene. Gregor started with polystyrene, nitrated it to form nitropolystyrene, reduced and diazotized the polymer, treated it with potassium ethyl xanthate, and then hydrolyzed it to produce poly-p-thiolstyrene.

The reactions of polythiolstyrene with different metals have been studied. This polymer is an extremely weak acid because of the contribution of the chain potential. It forms complexes with copper (II) only at high pH levels. Metals that form insoluble mercaptides react strongly with the polymer, however, in many cases being reduced directly to the metal, as in the case of silver (I), mercury (I) and (II), and lead (I) and (II). For example, treatment of the resin by solutions of silver nitrate in 0.01 M nitric acid results in a strong uptake of the silver ion, followed by its reduction, in certain cases, to metallic silver, for this polymer is also a strong reducing agent.

An interesting counterpart of the p-thiolstyrene resin has been formed by Miles *et al.*,[26] who prepared a specific reagent for mercaptans by

treating a phenolformaldehyde resin with mercuric acetate to prepare the compound shown below.



When this compound was treated with mercaptans such as cysteine or glutathione, a poorly dissociated complex was formed. These sulfur-containing amino acids were removed from solutions selectively. They could be eluted from the resin with hydrogen sulfide or other mercaptans.

Several attempts to prepare complexing resins by condensation reactions with aromatic complexing agents have been reported. Here considerable difficulties have been encountered because the condensation reactions yield heavily cross-linked and poorly defined resins wherever the proper steric configuration of the 2 monomers that make up the common quadridentate complex proves difficult if not impossible to achieve. Even when both groups are on the same monomer, the product may not be particularly useful.[27] Further work in this direction is indicated because of the ready availability of monomers and the experimental simplicity of the condensation reactions.

The question of unique specificity, that is, the ability of a chelate acid to react with only a single metallic species, is discussed in detail by Martell and Calvin,[9] who point out that truly specific complexation reactions are virtually unknown. Whether one is considering complexes with salicylaldehyde, ethylenediamine, dithiazone, the oxines, or the aminocarboxylic acids, there are normal sequences of formation constants with the different metallic ions. There is the well-defined sequence: $K < Li < Mg < Mn < Fe < Co < Ni < Cu > Zn$. Many authors have discussed the correlation between the formation constants with a given complexing agent and the properties of the bound metallic cations. Some authors plot formation constants as a function of the first ionization potential of the metal. Others use the second ionization potential, and still others make use of its electronegativity. Differences in binding appear to be, essentially, differences in degree.

There are no indications that specific binding with polychelates is essentially different from those effects observed with monomeric complexing agents. Polyelectrolytes appear to bind ions in the sequence given above. In certain complexation reactions where an insoluble precipitate is formed, the lattice energy of the precipitate contributes to the

free energy of the binding process, and the reaction can be fairly specific. In polychelate reactions where precipitates as such are not formed but, instead, only amorphous gels, such specificity would not be expected to exist.

Correlations with Biological Phenomena

The properties of polychelates account, in part, for the very strong binding of certain metallic cations by biological substances. Most metal binding in biological systems is effected by proteins and other natural polyelectrolytes. The chain potential is smaller in the case of proteins, but steric factors such as the presence of adjacent groupings can account for the strong binding observed.

The specificity of biological binding phenomena is difficult to explain by any analogy with synthetic systems. Accumulation of a metal against a high concentration gradient has, on the other hand, its counterpart in synthetic systems. For example, when traces of chromium (III) are present in saturated solutions of ammonium dihydrogen phosphate (about 5 M), the electrical properties of crystals grown from these solutions are inferior. It was found that a weakly cross-linked polyethyleneimin resin reduced the chromium (III) concentration from an initial level of 0.0002 M to 0.000004 M after a single batch equilibration at pH 4.[28] The very strong binding here is emphasized by the fact that chromium (III) is itself firmly complexed with phosphate, making its removal particularly difficult. This accumulative phenomenon is paralleled in biological systems by the concentration of respiratory pigment metals from sea water achieved by marine organisms.

Metal binding by naturally occurring polyelectrolytes also may be significant in membrane phenomena. The relative roles of the accumulation of a metal species by a membrane and the active transport of this species across the membrane have been discussed in connection with biological systems by many authors. A synthetic counterpart system was recently prepared by Gregor and Wetstone.[29] An Interpolymer membrane composed of a polycarboxylic acid and an inert film-forming plastic showed strong preferential transport to calcium over potassium, and the reverse effect for copper (II) and potassium. Conductance measurements showed that $\lambda_{K^+} > \lambda_{Ca^{++}} \gg \lambda_{Cu^{++}}$. The average mobility of potassium ions was about 4 times that of calcium, while copper was quite immobile. These results are consistent with pK_f values of calcium polyacrylate (10^3) and copper polyacrylate (10^7). Compared to potassium, calcium is accumulated strongly, but is not held so tightly as to be immobilized. Copper, on the other hand, is accumulated and held so strongly that it cannot migrate from one complexing site to another, and thus cannot conduct current. Therefore, a polyelectrolyte membrane can contribute to the specific transport of an ion by inducing the proper extent of accumulation.

References

1. FUOSS, R. M., A. KATCHALSKY & S. LIFSON. 1951. Proc. Natl. Acad. Sci. **37**: 579.
2. ALFREY, T., JR., P. W. BERG & H. MORAWETZ. 1951. J. Polymer Sci. **7**: 543.
3. KIMBALL, G. E., M. CUTLER & H. SAMELSON. 1952. J. Phys. Chem. **56**: 57.
4. LAZARE, L., B. R. SUNDHEIM & H. P. GREGOR. 1956. J. Phys. Chem. **60**: 641.
5. GREGOR, H. P., L. LUTTINGER & E. M. LOEBL. 1954. J. Am. Chem. Soc. **76**: 5879.
6. GREGOR, H. P. & M. FREDERICK. In preparation.
7. FUOSS, R. M. & D. EDELSON. 1951. J. Polymer Sci. **6**: 767.
8. HUIZENGA, J. R., P. F. GREIGER & F. T. WALL. 1950. J. Am. Chem. Soc. **72**: 2636, 4228.
9. MARTELL, A. E. & M. CALVIN. 1952. Chemistry of the Metal Chelate Compounds. Prentice-Hall. New York, N. Y.
10. GREGOR, H. P., L. B. LUTTINGER & E. M. LOEBL. 1955. J. Phys. Chem. **59**: 34.
11. SULLIVAN, J. C. & J. C. HINDMAN. 1952. J. Am. Chem. Soc. **74**: 6091.
12. GREGOR, H. P., L. B. LUTTINGER & E. M. LOEBL. 1955. J. Phys. Chem. **59**: 366.
13. GREGOR, H. P., M. J. HAMILTON, R. J. OZA & F. BERNSTEIN. 1956. J. Phys. Chem. **60**: 263.
14. GREGOR, H. P., J. BELLE & R. A. MARCUS. 1955. J. Am. Chem. Soc. **77**: 2713.
15. GREGOR, H. P. & K. A. BOWNES. In preparation.
16. BASTIAN, R. & H. P. GREGOR. In preparation.
17. JONASSEN, H. B. & A. W. MEIBOHM. 1951. J. Phys. Colloid Chem. **55**: 726.
18. GREGOR & D. H. GOLD. In preparation.
19. EDSALL, J. T., G. FELSENFELD, D. S. GOODMAND & R. N. GURD. 1954. J. Am. Chem. Soc. **76**: 3054.
20. GREGOR, H. P., D. H. GOLD & G. K. HOESCHELE. 1955. J. Am. Chem. Soc. **77**: 4743.
21. GREGOR, H. P. & D. H. GOLD. In preparation.
22. SKOGSEID, A. 1948. Dissertation. Aas & Wahl. Oslo, Norway.
23. CHEN, C. H., P. SPOERRI & H. P. GREGOR. In preparation.
24. GREGOR, H. P., D. DOLAR & G. K. HOESCHELE. 1955. J. Am. Chem. Soc. **77**: 3675.
25. OVERBERGER, C. G. & A. LEBOVITS. 1955. J. Am. Chem. Soc. **77**: 3675.
26. MILES, H. T., E. R. STADTMAN & W. W. KIELLY. 1954. J. Am. Chem. Soc. **76**: 4041.
27. GREGOR, H. P., M. TAIFER, L. CITAREL & E. I. BECKER. 1952. Ind. Eng. Chem. **44**: 2834.
28. GREGOR, H. P. Unpublished results.
29. GREGOR, H. P. & D. M. WETSTONE. Trans. Faraday Soc. In press.

SECTION OF GEOLOGY AND MINERALOGY

MARINE LEVEL-BOTTOM COMMUNITIES OF RECENT SEAS, THEIR TEMPERATURE ADAPTATION AND THEIR "BALANCE" BETWEEN PREDATORS AND FOOD ANIMALS*

By Gunnar Thorson

Zoological Museum, University of Copenhagen, Copenhagen, Denmark

Of the approximately 1 million species of recent animals known to man, only about 15 to 16 per cent are marine. A smaller fraction of these marine species are truly pelagic. The remainder, living on the bottom of the sea, comprise 2 ecologically distinct groups: the epifauna (all animals living *upon* the substratum, that is on rocks, shells, and vegetation) and the infauna (all animals living *in* the substratum, that is, dug down in the sandy, muddy, or mixed bottoms that, together, make up the level-bottom areas of the sea). Since the epifauna comprises more than four fifths of all bottom-dwelling animals, this means that the level-bottom areas, although occupying more than half of the surface of our globe, are inhabited by less than 3 per cent of all species of animals—a striking demonstration of their uniformity (Thorson, 1956). Among these 3 per cent only an astonishing small number of genera prove to be quantitatively dominant, and these genera will one day make the "guide fossils" for our period, as did the ammonites, belemnites, and trilobites in prehistoric seas.

For hundreds of millions of years these level-bottom areas and their infaunas must have covered much larger and much more uniform areas than the epifaunas. For this reason, if we wish to study the bottoms of recent as well as prehistoric seas from a quantitative point of view, we shall have to focus upon the level bottoms and their infaunas much more than upon the epifaunas, which may vary significantly from rock pool to rock pool.

Ecologically, the epifaunas and the infaunas behave quite differently. Typical epifaunal groups, such as amphipods, crabs, and prosobranchiate and nudibranchiate gastropods show a marked increase in their number of species from the Arctic toward the tropical seas, while pronounced infaunal groups, such as cumaceans, tectibranchiate gastropods (including *Cylichna*, *Philine*, and *Retusa*, and others), synaptid holothurians, and level-bottom brittle stars seem *not* to increase their number of species from the Arctic to the tropics. (Thorson, 1952).

In the Arctic seas the ratio between the number of epifaunal species and infaunal species seems, for most invertebrate phyla, to be approximately 50:50, while in a tropical coastal area or littoral zone the ratio will approach (80)90:(20)10—a figure that may be of some help to pale-

*This paper, illustrated with lantern slides, was presented at a meeting of the Section on May 7, 1956.

oecologists, who have to evaluate the temperature and the "ecological latitude" of the shells preserved in a fossil bed.

To give a detailed explanation of the ecological background for the differences between epifaunas and infaunas would lead us too far from the purpose of this paper, but it is evident that the epifaunas of, for instance, a tropical coral-reef zone have much better chances to develop a rich variation of species than do the epifaunas of an icy Arctic littoral zone, where all animal life is killed every winter, or of a cold-temperate littoral zone, where the large variations in temperature occurring throughout the year will exclude many species.

The areas that we have to focus upon here are the uniform, sandy or muddy level-bottom plains that are constantly covered with water. Such areas, fully inhabited by a rich infauna even in high-Arctic seas, will have approximately the same appearance and structure and will thus be a habitat for the same morphological types of infaunal animals wherever they occur, in Arctic, temperate, or tropical seas. The only fundamental difference between an Arctic and a tropical level bottom of the same type is the temperature of the water.

For more than 50 years these huge, uniform level-bottom areas and their infaunas have been studied, such quantitative equipment as the Petersen grab (Petersen, 1911) and the van Veen grab (Thamdrup, 1938) being used to procure samples. The thousands of samples now available from areas extending from the Arctic to the tropics have clearly demonstrated the remarkable fact that the same types of level-bottom substrata at similar depth are quantitatively dominated by invertebrates belonging to the same genera but to different species.

In mixed bottoms just below the littoral zone we find a "chain" of parallel *Macoma* communities quantitatively dominated by lamellibranchs of the genera *Macoma*, *Cardium*, and *Mya*, with different species replacing each other from the Arctic toward warmer seas.

In sandy bottoms in shallow water we find "chains" of parallel *Venus* communities quantitatively dominated by lamellibranchs of the genera *Venus*, *Tellina*, and *Spisula* or *Mactra*, different species replacing each other in accordance with latitude and temperature.

In muddy bottoms, at somewhat greater depth, we find chains of parallel brittle-star communities quantitatively dominated by the genera *Amphiura*, *Amphiodia*, or *Amphioplus*, the species replacing each other in a similar way.

We noted earlier that the only fundamental difference between level bottoms of the same type in different latitudes was the temperature. Experiments have shown, however, that these quantitatively dominating species of the same genera replacing each other in a chain of parallel communities are nearly or fully adapted to the temperatures of the latitudes in which they normally occur (Spaerck, 1936; Thorson, 1936, 1952; and Bullock, 1955). Since, however, these replacing species actually

make the communities, this means that the parallel communities are also adapted to the temperature of the areas in which they occur. In other words, an arctic *Macoma* community at 0° C. shows, roughly, a similar metabolic rate, a similar rate of growth, and similar feeding habits, as a boreal *Macoma* community at 8°C., or a Mediterranean community at about 12° C., or a tropical community at a still higher temperature. This means that any observations on predation, mode of feeding, competition, or growth made at any specific coastal area may be of direct help in explaining similar phenomena in other similar communities.

The uniformity of recent chains of parallel communities seems so striking and so convincing that it is much more than a newly established phenomenon valid for recent seas only. Since the uniformity of level-bottom areas existed also in prehistoric seas, and since level-bottom species have had huge periods of time in which to establish and adapt themselves, it seems reasonable to assume that prehistoric seas within the same geological eras have also been inhabited by such series of parallel level-bottom communities. To the paleoecologists a chain of, for instance, cretaceous parallel level-bottom communities may prove to be as useful as recent communities have proved to be to modern marine biologists, since any observation from any parallel within a chain might help him to explain, to understand, and to be on a lookout for links lacking in fossil collections from another parallel bed. Here there is certainly a wide and, until now, unexplored hunting ground for paleoecologists.

Our experience with recent level-bottom communities might perhaps also be of some value to paleoecologists in building up a logical understanding of an entire prehistoric level-bottom community on the basis of the shells found in a fossil bed. Let us see how a marine biologist might attack this problem today.

First he has to find a method of distinguishing between epifaunal species and infaunal species, remembering that the latter group represents must larger and much more uniform areas and may, therefore, not only tell him much more but allow him to generalize his conclusions more freely than would the information afforded by the epifaunal species. Epifaunal lamellibranchs are, in most cases, fixed to their substratum by byssuses. This mode of attachment often leaves a small impression in the ventral margin of the shell. All sessile animals are epifaunistic. Groups such as crabs and prosobranchiate gastropods are mostly epifaunistic. Starfish of the sucking-disc type are epifaunistic and, in their whole shape and construction, they are much different from the infaunal species. Knowledge of such facts makes it possible for paleoecologists, after some training, to distinguish between epifaunal fossils and infaunal fossils.

Having thus isolated the infaunal species for a detailed study, the next thing to do is to focus upon the "key animals," that is, the animals

transforming vegetable matters into meat and thus serving as food for the predators. These key animals, constituting the lowest animal link of the "food chain," the broad basis of the "food pyramid," are, in most cases, quantitatively dominant, and they often comprise a large number of lamellibranchs that are easy to find and to identify in most fossil beds.

These infaunal lamellibranchs may provide other valuable information. Among recent lamellibranchs we distinguish between "suspension feeders," having 2 siphons that are always of about the same length and taking their food—the phytoplankton—from free water, and "deposit feeders," having 1 short and 1 much longer siphon, the latter being used like the hose of a vacuum cleaner to suck up their food—the detritus—from the bottom. Although the technique is still far from elaborated, it seems probable that a detailed study of the adhesion scars of the retractor muscles from the siphons on the interior side of the lamellibranch shells may give us information about the "feeding type" that has been used in each species of lamellibranch, even in species from prehistoric seas. Suspension feeders dominate on sandy bottoms. In most cases, sandy bottoms are found in turbulent waters, close to the surface and, accordingly, there are greater variations in temperature and salinity. Deposit feeders dominate on muddy bottoms that, in most cases, sedimentate at greater depth, thus indicating a more stable temperature and salinity.

These lamellibranch shells may often also reveal, by their markings, certain information about the dominant predators. Gastropod predators, such as *Natica*, *Polynices*, *Thais*, or *Urosalpinx*, drill holes of fairly different shapes in the shells of their prey. Gastropods such as *Busycon* or *Murex* break the margin of their lamellibranch prey in a very characteristic way. Crabs make typical fractures of the margins of the clam shells on which they feed. Studies of such feeding habits of recent predators may support the paleoecologist with much useful information. On the other hand, starfish and brittle stars do not seem to fossilize very well, and they leave no markings on the shells of their prey. Here, however, a *comparison* of parallel prehistoric communities may offer the paleoecologist much help. Most recent parallel communities have predator specialists belonging to the same genera. Each *Venus* community seems, for instance, to have a starfish predator of the *Astropecten* type. Most likely this parallel relationship would also have been the case in prehistoric communities and, if the predators from 1 parallel are known, there is a greater likelihood that the investigator will be on the lookout for remnants of them in other parallels (such remnants as individual spines or marginal plates of the starfish, for instance, that the paleoecologist would hardly look for if he did not know that he had a reasonable chance of finding them).

Having realized the value, quite technically, of teamwork studies of

the parallel level-bottom animal communities of recent—and probably also prehistoric—seas, it seems reasonable to ask how such a level-bottom community, in the sense described by C. G. Joh. Petersen (1911, 1913, and 1918), is established.

From cold-temperate to tropical seas most invertebrates inhabiting the bottom of the sea have a very hazardous pelagic larval life. Different species of larvae will perish or survive, until metamorphosis occurs, in different years. The level-bottom communities are recruited from this surviving set of larvae (Thorson, 1950). Furthermore, the narrow, horizontal stratification of the larvae in free water, even when they are ready to settle, is responsible for the fact that only a select and often very reduced set of larvae achieve contact with each type of sea bottom. The population of a level-bottom community, therefore, must be recruited from this narrow set of existing probabilities.

Wilson (1937, 1948, and 1952) found that larvae of the polychaetes ready to settle will examine critically the bottom substratum to which they are exposed (we now find this true of many other larval invertebrates). Such larvae will settle and metamorphose if they find the substratum attractive, but they will postpone settling and continue their pelagic life for days or even weeks if they find it repellent. Drifting along and testing the bottom at intervals, they thus have good chances of finally finding an attractive substratum. The size of the grains of sand of the substratum and even the shape of the grains may play an important part in the attractiveness or unattractiveness of a substratum. But this is only part of the story. Other matters, such as excretions or secretions of animals already present, or tough proteins adhering to particles of the substratum seem to exert an influence upon the "choice" made by the larvae.

Nevertheless, the substratum is the master factor responsible for the composition of the fauna and thus for the qualitative composition of the level-bottom animal communities. A larva that has settled by free choice on a substratum that is floated by a water mass to which it naturally belongs, will become more resistant to changes in salinity and temperature as it grows older and will therefore, in most cases, in the open sea, be able to tolerate the physical-chemical environment to which it is exposed for the rest of its life. After settling, however, another crisis occurs—the biological fight between the selected set of species comprising each level-bottom community. Each of these communities has its hunted animals and its predators, and it is necessary to understand the balance between these 2 groups if we wish to understand the mechanics of such a community.

First, more knowledge about the quantity of food consumed by the different predators is urgently needed. Summarizing the few recorded facts from the literature on this subject (Dawes, 1930, 1931; Bückmann,

1952; Pearse, 1924; and Hathaway, 1927), we find that, in temperate waters during the summer, a bottom-dwelling predator fish will consume an average portion of food per day corresponding to about 5 per cent of its own weight. It is thus not too voracious in its feeding habits.

If we now turn from fishes to invertebrate predators we find a remarkable contrast. Facts based on the literature and on my own calculations (to be published) have shown that invertebrate predators within such groups as prosobranchiate and tectibranchiate gastropods, polychaete worms, starfish, and crabs will have an average consumption of food that is 4 times as high per day and weight unit as that of the bottom-dwelling vertebrates.

This is not as astonishing as it might at first appear, since the life cycles of nearly all of these invertebrate predators are much shorter than those of the bottom-dwelling fishes. Often the life cycle of one generation of fish will correspond in span of time to that of 3 to 4 generations of invertebrate predators and, accordingly, the invertebrate predators growing to full size during a much shorter time will have to consume more food.

Such voracious invertebrate predators are often present on the bottom in enormous quantities. Off the Atlantic coast of Canada we have reports on a density of starfish of as many as 15 specimens per square meter of bottom (Smith, 1940). Most of the parallel *Amphiura* communities replacing each other on muddy bottoms throughout the world have an average of 400 to 500 brittle stars per square meter. The arms of these voracious predators make a network over the bottom so dense that each square centimeter of bottom will be examined at least once every 24 hours by the arms of a predator. The question therefore arises: How is it possible for the small larvae of such groups as lamellibranchs, gastropods, or polychaetes, when they leave free water to settle between this network of voracious predators without being discovered and eaten in less than 24 hours?

We know, however, that the small larvae do manage to settle, and several quantitative samples have demonstrated rich populations of thin-shelled, adult lamellibranchs (*Syndosmya, Cultellus*) apparently thriving well between the whorling crowds of brittle stars.

The explanation of this phenomenon is surprising. In a temperate sea (the Swedish-Danish Sound) the spatfall of all the lamellibranchs, prosobranchs, and polychaetes on the muddy bottoms reaches its summit in the late summer, that is, just when the brittle stars lose their appetites because they are preparing to spawn. At this time of the year the small disc of the brittle star is fully distended by the swollen gonads. The stomach is pushed aside, and the stomach wall may even undergo histolysis. This process of "loading up" for spawning lasts about one month. As soon as spawning is over, the digestive apparatus has to be repaired and, during this time, the brittle stars lie apathetically on the

bottom, not responding to such stimuli as, in other seasons, would make them crawl in lively fashion over the bottom (Thorson, 1956).

This natural quiescent period, during which the predators lose their appetites and the animals on which they prey grow at their quickest rate, together with the influence of the substratum, accounts for the balance and the qualitative as well as the quantitative composition of the adult brittle-star communities.

We now have facts about similar periods of suspended appetite during the breeding seasons of several more species of invertebrate predators, and the coming years no doubt will prove that this factor is an essential mechanism regulating the balance between predators and prey on the sea bottom.

The discovery of these periods during which brittle stars in the *Amphiura* communities lose their appetites gives an instructive illustration of the advantages that might be obtained in the future by teamwork on parallel communities. Thus far very little has been done along these lines along the coastal areas of the United States, but a comprehensive mapping survey of level-bottom communities along the Atlantic coast from Maine to Florida and westward along the coast of the Gulf of Mexico as far as the Mississippi is now planned and will probably be started in the near future. This survey promises to yield much valuable knowledge.

References

BULLOCK, T. H. 1955. Compensation for temperature in the metabolism and activity of poikilotherms. Biol. Revs. Cambridge Phil. Soc. **30**(3): 311-342.

BÜCKMANN, A. 1952. Vorläufige Mitteilungen über Fütterungs- und Wachstumsversuche mit Schollen im Aquarium. Kurze Mitt. Max Planck-Instit. Meeresbiol. **1**: 8-21.

DAWES, B. 1930. Growth and maintenance in the plaice (*Pleuronectes platessa* L.) Part I. J. Marine Biol. Assoc. United Kingdom. **17**: 103-174.

DAWES, B. 1931. Growth and maintenance in the plaice (*Pleuronectes platessa* L.) Part II. J. Marine Biol. Assoc. United Kingdom. **17**: 877-947.

HATHAWAY, E. S. 1927. Relation of temperature to quantity of food consumed by fish. Ecology. **8**: 428.

PEARSE, A. S. 1924. Amount of food eaten by four species of freshwater fishes. Ecology. **5**: 254-258.

PETERSEN, C. G. JOH. 1911. Valuation of the sea. I. Animal life of the sea bottom, its food and quantity. Rep. Danish biol. Sta. **20**.

PETERSEN, C. G. JOH. 1913. Valuation of the sea. II. The animal communities of the sea bottom and their importance for marine zoogeography. Rep. Danish biol. Sta. **21**.

PETERSEN, C. G. JOH. 1918. The sea bottom and its production of fish-food. Rep. Danish biol. Sta. **25**.

SMITH, G. F. M. 1940. Factors limiting distribution and size in the starfish. J. Fisheries Research Board. Can. **5**: 84-103.

SPAERCK, R. 1936. On the relation between metabolism and temperature in some marine lamellibranchs, and its zoogeographical significance, K. Danske Videnskab. Selskab, Biol. Medd. **13**(5): 1-27.

THAMDRUP, H. M. 1938. Der van Veen-Bodengreifer. Vergleichversuche über die Leistungsfähigkeit des van Veen- und des Petersen-Bodengreifers. J. conseil, permanent intern. Exploration mer. **13**(2): 1-8.

THORSON, G. 1936. The larval development, growth and metabolism of arctic marine bottom invertebrates. Medd. Grønland. **100**: 1-155.

THORSON, G. 1950. Reproductive and larval ecology of marine bottom invertebrates. Biol. Revs. Cambridge Phil. Soc. **25**: 1-45.

THORSON, G. 1952. Zur jetzigen Lage der marinen Bodentier-Ökologie. Verhandl. deut. zool. Ges. **1951**: 276-327.

THORSON, G. 1956. Modern aspects of marine level-bottom animal communities. J. Marine Research Sears Foundation. In press.

WILSON, D. P. 1937. The influence of the substratum on the metamorphosis of Notomastus-larvae. J. Marine Biol. Assoc. United Kingdom. **22**: 227-243.

WILSON, D. P. 1948. The relation of the substratum to the metamorphosis of *Ophelia* larvae. J. Marine Biol. Assoc. United Kingdom. **27**(3): 723-760.

WILSON, D. P. 1952. The influence of the nature of the substratum on the metamorphosis of the larvae of marine animals, especially the larvae of *Ophelia bicornis* Savigny. Ann. inst. océanog. Paris. **27**(2): 29-156.

SECTION OF BIOLOGY

I. A NEW AND RAPID METHOD FOR ISOLATING VIRUSES BY SELECTIVE FLUOROCARBON DEPROTEINIZATION*

By Albert E. Gessler, Charles E. Bender,** and Martin C. Parkinson**

The Research Laboratories of Interchemical Corporation, New York, N. Y.

In a previous paper we have described a method for the segregation of viruslike bodies from cancerous animal tissues by the use of nonpolar organic solvents that form emulsions with aqueous liquids containing highly dispersed tissues. These solvents were selected in order to have greater control over the specific gravity and viscosity of the isolating medium and, at the same time, to avoid the difficulties usually encountered in aqueous systems.

We had first selected monochlorbenzene for the organic solvent since its low viscosity and specific gravity of 1.1 produced the effect that long periods of high centrifugation were avoided. In a search for solvents similar but possessing an absolute minimum of toxicity, we found the fluorocarbons to be highly suitable. Particularly, the toxicities of Freon 112† (CCl_2F-CCl_2F) or Genetron 226‡ (CF_2Cl-CCl_2F), are of the order of that of carbon dioxide. Their specific gravities of 1.6 allowed easy adjustment with an admixture of n-heptane to resemble the specific gravity of proteins. N-heptane is a saturated hydrocarbon possessing a density of Ca. 0.7, and the qualities and low toxicity of petrol ether (n-hexane). The latter hydrocarbon has been frequently mentioned in the literature as a useful agent to use in extracting fat without affecting the viability of viruses contained in the tissue. The surface tensions of both Freon 112 and Genetron 226 are very low, producing the effect that their emulsions with water break easily and cleanly upon standing or at low-speed centrifugation.

For a suitable test virus we selected vaccinia virus grown on the chorioallantoic membranes of 11-day-old fertile chicken eggs. The homogenization of the infected membranes and the segregation of the viruses contained in them required a total time of less than 2 hours. The viability of the obtained vaccinia viruses compared very favorably with our controls. In reality, dilutions could be made after our Freon-heptane treatment that showed a titer of 10^{-9}, while our control showed a titer of 10^{-7}. In view of the ease of operation of this method and the freedom of the isolated viruses from nonviral proteins and lipids, we believe that the

*This paper, illustrated with lantern slides, was the first of 3 papers presented at the meeting of the Section on May 14, 1956, on The Isolation of Viruses by a New and Rapid Method.

**Present address: The VirTis Company, Inc., Yonkers, N. Y.

† Obtained from the "Kinetic" Chemical Division, E. I. DuPont de Nemours & Co., Inc., Wilmington, Del.

‡ Obtained from the Division of Allied Dye and Chemical Corporation, General Chemicals, Inc., New York, N. Y.

process may be generalized, and so may find utilization as a new method for virus assay and virus isolation in general. Further work has shown that this technique is adaptable for the isolation of the Rous virus in extremely pure form.

Materials. McIlvaine's standard citrate buffer at pH 7.4 diluted 1:50 with distilled water. Freon-heptane mixture--specific gravity 1.25--75.0 gm. Freon 112, 25.0 gm. n-heptane. Vaccinia-infected chorioallantoic membranes of fertilized chicken eggs inoculated at 11 days and harvested after 72 hours incubation at 37° C. Inoculation per egg was 0.2 ml. Later studies indicated that with the use of Genetron 226, the addition of n-heptane was not necessary, since Genetron 226 completely replaced the Freon-heptane mixture.

Method. Two gm. of vaccinia-infected chorioallantoic membranes, 5.0 ml. of the Freon-heptane mixture, and 10.0 ml. of the 1:50 McIlvaine's citrate buffer are homogenized in a VirTis homogenizer, Model 6-105* for 10 minutes at 23,000 r.p.m. The entire homogenate had a pH of 7.20. The milklike, practically foamless homogenate is then centrifuged at 1800 r.p.m. (750 g) for 5 minutes, during which it separates into 3 sharply defined layers. (It is also possible to eliminate the centrifugation completely by allowing the homogenate to stand for several hours in the refrigerator. The emulsion break is as clear and sharp as it is when made by centrifuging.) The aqueous middle layer is carefully removed and stored. In order further to liberate large amounts of virus particles, add to the remaining creamlike top and bottom layers 10.0 ml. of the dilute buffer solution and homogenize again at 23,000 r.p.m. A single homogenization for a prolonged period of time is much less efficient in freeing the viruses in a high state of purity. Centrifuge this second homogenate at 1800 r.p.m. (750 g) for 5 minutes. Again remove the middle clear aqueous portion and discard the more solid top and bottom layers. Combine the 2 aqueous portions and, after adding 5.0 ml. of new Freon-heptane mixture, homogenize for a third time at 23,000 r.p.m. for 10 minutes. Centrifuging this homogenate at 750 g for 5 minutes results in a water-clear supernatant that contains the viruses in a state of remarkable purity and freedom from lipids and nonviral proteins contained in the same tissue.

Summary

A simple and rapid method is described for the segregation of virus particles in tissue homogenates by selective fluorocarbon deproteinization. These emulsion systems offer astonishingly efficient means by which to gather and hold the nonviral proteins and lipids of homogenized virus-bearing tissue in their organic phase, while concentrating the viruses in the aqueous phase. Vaccinia virus is used as an example.

*Obtained from The VirTis Company, Inc., Yonkers, N.Y.

Reference

GESSLER, A. E., K. S. MCCARTY, M. C. PARKINSON & J. M. BARDET. 1949. Exptl. Med. Surg. 7: 4.

II. EVALUATION OF A FLUOROCARBON TECHNIQUE FOR THE ISOLATION OF PLANT VIRUSES*

By Clark A. Porter

Boyce Thompson Institute for Plant Research, Inc., Yonkers, N. Y.

Procedures for the isolation and purification of plant viruses involve maceration of infected tissue, removal of large particles by filtration or pressing through several layers of cheesecloth, and then clarification of the resulting infective juice in order to remove nonviral constituents. Clarification is accomplished in part by treatment of the juice with Na_2HPO_4, heat, or ethanol. These treatments bring about coagulation of much of the plant material. Further purification is carried out by salt precipitation or by differential centrifugation. More recently the initial step in clarification has been accomplished by emulsifying the infective juice with chloroform,[1] *n*-butanol,[2] or a mixture of the 2 compounds.[3] The emulsions are broken by centrifugation, and the virus is contained in the aqueous phase. Ultracentrifugation may be employed to sediment the virus from residual contaminants in the aqueous phase. These techniques are rapid for virus assay and have yielded virus of high purity.

Certain fluorocarbon compounds have been used recently in the isolation of various animal viruses.[4] Because of their chemical inertness and their relative nontoxicity, it was believed that such materials might prove ideal for plant virus purification. For this reason the uses of 2 fluorocarbon compounds for the purification of tobacco mosaic virus has been investigated.

The initial experiments were conducted using a 3:1 mixture of Freon 112 ($C_2F_2Cl_4$) and *n*-heptane. Genetron 226 ($C_2F_3Cl_3$), however, was used in most of the subsequent experiments. Since no differences were detected between the results obtained with the Freon 112 mixture and Genetron 226, further discussion will be facilitated by using the term fluorocarbon when referring to either compound.

The procedure for purification of tobacco mosaic virus consisted of homogenizing infected tobacco tissue directly in a system containing the fluorocarbon and 0.01 M phosphate buffer at pH 7.0. In general, the proportions used were: 1 gm. tissue, 4 ml. buffer, and 10 ml. fluorocarbon. Homogenization was carried out in a VirTis 45 homogenizer operating at top speed for 1 to 5 minutes. The emulsion was centrifuged for 5 to 10 minutes at about 1000 g, resulting in the separation of 3 distinct layers. The upper aqueous layer was found to contain the virus, the lower fluorocarbon layer contained chlorophyll, and the center compact plug formed by the fluorocarbon-buffer gel contained protein and cellular

*This paper, illustrated with lantern slides, was the second of 3 papers presented at the meeting of the Section on May 14, 1956, on The Isolation of Viruses by a New and Rapid Method.

debris. The virus was then further purified by ultracentrifugation to sediment it from contaminants in the aqueous phase, and it was assayed by a spectrophotometric method.[5]

This fluorocarbon method of isolation and purification of tobacco mosaic virus was compared with chloroform emulsification (as previously described), with a "heat-ultra" method,[6,7] and with a trypsin digestion method.[8] The fluorocarbon method was found to yield more tobacco mosaic-virus protein than the other methods. Infectivity, expressed on a tissue-concentration basis and assayed by local-lesion development on pinto beans, was found to be higher following fluorocarbon emulsification than when homogenized in buffer only. It is concluded that the described method yields more active virus from infected tissue than the methods with which it was compared.

The optimum homogenizing time for tobacco mosaic-virus-infected tobacco tissue was 4 to 5 minutes at top speed. The extraction of virus appeared complete in the first homogenization, with subsequent treatments showing no significant increase in recovered virus.

In order to measure the efficiency of this method for the removal of plant proteins from virus preparations and to determine if normal nucleoproteins might also be released from the tissue, healthy tobacco tissue was subjected to the fluorocarbon procedure, and the distribution of protein nitrogen and nucleic acid phosphorus was determined. As compared with homogenates prepared in buffer only, fluorocarbon treatment was found to reduce the protein-nitrogen content of the aqueous phase considerably, without affecting the nucleic-acid phosphorus concentration to the same degree. An additional homogenization of the aqueous phase with fresh fluorocarbon further reduced the protein nitrogen and nucleic acid phosphorus. The protein nitrogen was reduced by 90 per cent, while the nucleic acid phosphorus was reduced by only 38 per cent. This indicates that protein was removed from the aqueous phase much more effectively than nucleic acid phosphorus.

When tobacco mosaic virus-infected tissue was subjected to 2 treatments with fluorocarbon, about 25 per cent of the virus was lost in the second emulsification. Since this treatment also removed extraneous protein, the virus obtained was in a state of higher purity.

The conditions used in these experiments were those normally employed for virus isolation, in which the plant constituents should be completely eliminated. The data obtained, however, indicate that the fluorocarbon emulsification procedure, if used properly, may also be effective for extracting nonviral nucleoprotein from plant tissues.

Two other plant viruses, tobacco ringspot virus and common cucumber mosaic virus, were subjected to the isolation procedure. Fluorocarbon preparations of tobacco ringspot virus, compared with buffer homogenates, gave higher local lesion counts on black cowpeas and higher absorption

at 260 mμ. This indicates that more virus was liberated from the tissue through fluorocarbon treatment than with homogenization in buffer. Similar comparisons made with cucumber mosaic-virus-infected tissue were found to give a higher level of infective virus in the buffer homogenates. In this case the fluorocarbon preparations exhibited little or no infectivity. Tissue macerated in buffer with a mortar and pestle and then emulsified with fluorocarbon by shaking was also less infective than buffer homogenates, but it was considerably more infective than the preparations made with high-speed homogenization in fluorocarbon. It appears that infectivity is destroyed or inhibited in some manner in this latter treatment. The anomalous behavior of cucumber mosaic virus is being further investigated.

References

1. SCHNEIDER, I. R. 1953. Solution of tobacco mosaic virus in the aqueous phase of a chloroform-water emulsion and application of this phenomenon in virus assay. Science. **117**: 30-31.
2. STEERE, R. L. 1953. Tobacco ringspot virus, a polyhedron, purified with the use of butanol. Phytopathology. **43**: 485.
3. STEERE, R. L. 1956. Purification and properties of tobacco ringspot virus. Phytopathology. **46**: 60-69.
4. GESSLER, A. E., C. E. BENDER & M. C. PARKINSON. 1955. Personal communication.
5. TAKAHASHI, W. N. 1951. Ultraviolet absorption as a measure of tobacco mosaic virus nucleoprotein. Phytopathology. **41**: 142-145.
6. SCHLEGEL, D. E. & T. E. RAWLINS. 1953. A comparison of two methods of preparing tobacco mosaic virus for spectrophotometric assay. Phytopathology. **43**: 89-91.
7. SCHLEGEL, D. E. & T. E. RAWLINS. 1954. A screening test of the effect of organic compounds on production of tobacco mosaic virus. Bacteriol. **67**: 103-109.
8. TAKAHASHI, W. N. 1951. A comparison of methods for extracting tobacco mosaic virus from leaf tissue. Phytopathology. **41**: 903-907.

III. ANIMAL VIRUSES ISOLATED BY FLUOROCARBON EMULSIFICATION*

By Albert E. Gessler, Charles E. Bender,** and Martin C. Parkinson**

The Research Laboratories of Interchemical Corporation, New York, N. Y.

In 2 accompanying papers we have described a method for the isolation of animal viruses by fluorocarbon emulsification. Vaccinia virus and Rous sarcoma fowl virus had been selected for test materials. They were chosen because they can be grown easily and because their dimensions represent 2 extremes of virus sizes. Vaccinia virus is one of the largest whose bricklike shape has the average dimensions of 250 × 350 mμ. Rous virus is of globular form, and its size, as isolated by our method, is near the threshold of visibility of the electron microscope, which is approximately 5 mμ. Notwithstanding this 1:50 difference in linear-size levels, the Freon-heptane emulsification technique worked equally well in either case, producing what we believe to be satisfactory results as to the ease of the method and the purity of the segregated viruses. Some unreported forms of the Rous virus were observed, and a discussion of the experimental procedure and the results seems necessary.

With the availability of an efficient method for the separation of nonviral proteins from the nucleoproteins of virus particles, a very thorough mincing and homogenization of virus-bearing tissue becomes practicable. It becomes of great importance because a high degree of homogenization can logically produce richer viral material, this material being more readily set free from the tissue in which it was bound or locked up. Such homogenization, however, can be utilized only if a subsequent segregation process can accomplish the full separation and elimination of the also finely homogenized lipids and nonviral proteins. Since these latter materials are the major part of the homogenate, they severely interfere in general with attempts to isolate the viral material in a form pure enough to observe and evaluate its true characteristics.

The Freon-heptane emulsification method of our process seems able to effect a satisfactory and rapid segregation of the milklike homogenate that is produced by the thorough action of a high-speed knife homogenizer. In the sedimentation step of the process the viral material is concentrated in a clear, aqueous middle phase, while the nonviral proteins separate in a heavy Freon-heptane bottom layer. Because of the high solvent power of these solvents for some fats, a part of the lipids is in solution in the bottom layer, while other and more insoluble lipids cream off in a thin top layer. The dissolved fats can be separated by filtration

*This paper, illustrated with lantern slides, was the third of 3 papers presented at the meeting of the Section, May 14, 1956, on The Isolation of Viruses by a New and Rapid Method.

**Present Address: The VirTis Company, Inc., Yonkers, N. Y.

from the nonviral proteins that are also contained in the bottom layer. The middle layer is cleanly bounded and separated from the other 2 layers, and it can be removed easily with a pipette. It possesses a high infecting power upon inoculation into fertile eggs or young chickens.

The behavior of these emulsions in forming easily during the homogenization process and then separating cleanly into 3 layers, each containing segregated constituents of the homogenate, is an interesting phenomenon. It could be explained in the light of the physical chemistry of surfaces and the "wetting power" of different liquids upon surfaces.[1] Evidently the surface of viral protein particles is preferentially wetted or attracted by water, while nonviral protein particles are preferentially wetted or attracted by the solvents in our system. As an example, it may be remembered that the process of mineral flotation that is used on a vast scale in ore mining is dependent upon preferential wetting for its success. In the ground mineral material the ores, like the sulfides of copper or zinc, are preferentially attracted by and accumulated in 1 part of the flotation liquid, while the accompanying rock particles are attracted by and accumulated in another part of the liquid. Thereby pure ore can be separated easily from the bulk of the rock.

The time required for the execution of our process is comparatively short. The homogenization of the infected tissue and the segregation of the viruses contained therein required a total time of 1 to 2 hours. The viability of the obtained vaccinia viruses compared very favorably with our controls.

In the case of the much smaller Rous sarcoma virus, whose isolation was our real aim, the segregation process offered no difficulties and took the same course. The virulence of the agent contained in the aqueous layer was high. Our electron micrographs showed particles of 2 size levels—larger particles of 40 to 70 mμ in diameter, with a background of particles 5 to 10 mμ in diameter (FIGURE 1).

The dimensions of Rous sarcoma virus have been studied by a number of investigators with widely varying results. The literature on these studies reports virus sizes ranging from diameters of 200 mμ down to one tenth of this. Even individual investigators have described size variations within wide limits.

It appears, however, that some of the observers were able to report a preponderance of viruses in size levels from 80 mμ down to 20 mμ. In a previous paper,[2] based on electron microscopic measurements in Rous tumor sections and segregations, we expressed the belief that the 20-mμ particles observed are basic or elementary bodies. In view of this apparent disagreement in the literature, Kahler *et al.*[3] state that the answer to the different particle sizes of the virus derived by their calculations "must await the preparation of a highly purified virus preparation."

The above-mentioned occurrence of 2 levels of virus dimensions in

our aqueous layer attracted our attention very strongly. In order to accomplish a separation of the 2 levels, the virus-bearing phase, after Freon-heptane treatment, was subjected to ultracentrifugation. Twenty hours of centrifugation at 144,000 g resulted in the sedimentation of a

FIGURE 1. Supernatant of Freon-heptane separation treatment. Two levels of particle sizes are portrayed: larger particles with diameters of 40 to 70 mμ and smaller particles of 5 to 10 mμ. Note that some large particles show signs of being aggregates. Air-dried and shadowed at 10° angle. ×45,000.

slight solid pellet at the bottom of a clear supernatant. No top layer was discernible. When bioassays of the supernatant and pellet were carried out, a very unsuspected outcome was observed. No apparent difference could be established in the high tumor-producing activity of the top, middle, and bottom layer of the clear supernatant when they were injected into the chorioallantoic membrane of fertile eggs. The massive tumors resulting from the inoculations could be harvested after 2 to 3 days where, before ultracentrifugation, 4 to 5 days were required to produce similarly massive tumors. This supernatant, containing McIlvaine's buffer in 1:50 dilution, possessed a specific gravity of 1.004. In contrast to the supernatant, the pellet was found to possess much less virulence. The nitrogen content of the pellet was determined to be 12.24 per cent N.

A repetition of the process through a second and third generation in eggs produced, upon inoculation with the supernatants, the same typical results of massive tumor growth. The final tumors appeared to be identical with those of the first and second generation. Their histological examination* showed typical myxomatous formation and spindle cells of Rous sarcoma (FIGURES 2, 3, and 4). Dilutions of the material to a titer of 10^{-8} still showed unmistakable sarcoma formation. Our electron micrographs of the supernatant showed a profusion of spherical particles with diameters of 10 to 20 mμ, and some of larger dimensions (FIGURES 5 and 6).

The fact that particles of both size levels were not sedimented in a field of such massive centrifugal force was unexpected and distinctly surprising as was the exceptionally high virulence of the supernatant. Authorities in the field have found the Rous agent to be easily sedimented. In attempting an explanation, the following may be offered:

If it is assumed that the agent present in the clear centrifugate is a virus, it would be tenable to reason that, in view of the variations in dimensions reported in the literature, the large particles may be aggregates of a number of small particles. They may be cemented or held together by proteins. It would then be understandable that upon loosening or removing the cementing materials, as by the process of severe homogenization and subsequent Freon-heptane emulsification, a disbanding or liberation of the small particles would take place. One particle of 70 mμ diameter could theoretically disband into about 3000 particles of 5-mμ diameters. A number of smaller particles could be expected to possess higher virulence than the 1 large original particle even if due to increased surface alone. The nonviral and cementing proteins may be higher in density than the virus particles, otherwise they could not form a pellet during ultracentrifugation. Being ballast material, their removal from the viral material would tend not only to reduce the latter's specific gravity but also to increase its virulence. A still greater possi-

*The histological examination of the tumors was carried out by Anthony Rottino of St. Vincent's Hospital of the City of New York, New York, N. Y.

bility is that, by our isolating technique, some inhibiting materials may be removed.

A study of sedimentation figures supports the nonsettling of the small particles and, thereby, their continued presence in the clear supernatant as we have ascertained it in our electron micrographs.

In the following table,[4] F represents the centrifugal force (in multiples of g) necessary to sediment particles of different radii (r) and a specific gravity of 1.10 through 1 cm. of water during 1 hour.

r in mμ	F
20	40,000
10	150,000
6	500,000
4	1,000,000
1	15,000,000

A study of these figures will disclose 2 or 3 possibilities. The highly active agent contained in the final centrifugate may occur in a particle size less than approximately 10 mμ and a density not higher than 1.1 in

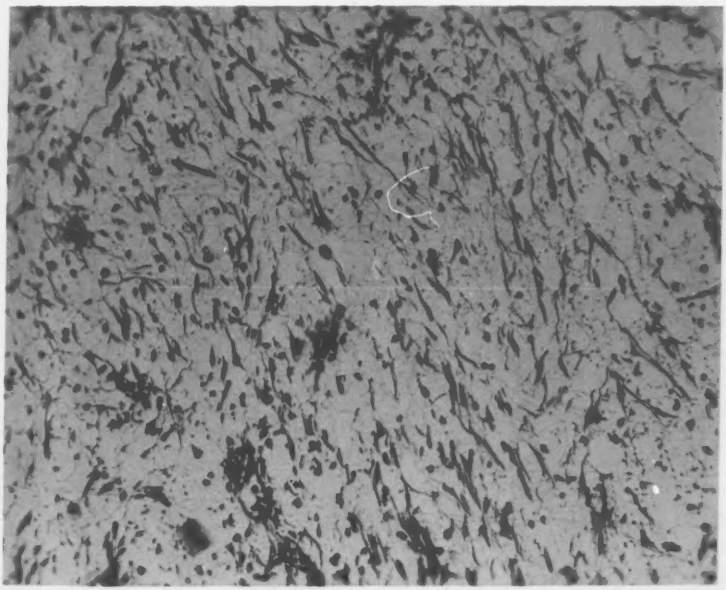


FIGURE 2. Section of a first-generation tumor grown on the chorioallantoic membrane of a fertilized chicken egg inoculated with homogenate of Rous sarcoma tumor obtained from the National Cancer Institute, National Institutes of Health, Public Health Service, United States Department of Health, Education and Welfare, Bethesda, Md. Note the myxamatous appearance of the tissue, with spindle cells predominating.

order not to be affected by the pull of 144,000 g during 20 hours. If the highly active agent should be represented by the larger particles, however, its density must be considerably lower than 1.1. Such a low density would be somewhat difficult to accept in view of other density figures determined for viruses in general, and another explanation should be looked for.

The literature is limited in density figures for the Rous sarcoma virus. One of the most recent papers is by Kahler *et al.*,[3] in which these investigators mention "the large amount of non-viral material now known to be present in simple centrifugally prepared specimens, so that their density values cannot be given much weight." Upon sedimentation of their more carefully prepared viral material through specific-gravity zones ranging from 1.175 down to 1.15, these investigators found that varying amounts of the virus were in most of the fractions, with a maximum in the specific-gravity level of 1.15. Yet a firm pellet "of heavy protein aggregates" had still sedimented in the 1.18 layer during a 3-hour centrifugation at 100,000 g. The electron micrographs of our ultracentrifuged supernatant show the presence of particles of both size levels in a medium of 1.004 density. A closer study of these particles discloses,

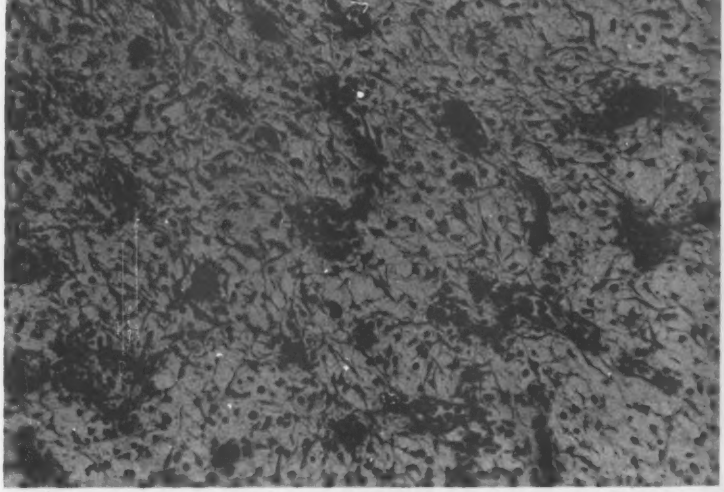


FIGURE 3. Section of a second-generation tumor grown in a fertilized chicken egg inoculated with supernatant of ultracentrifugate prepared from the tumor described in FIGURE 2. Note that the appearance is identical to that shown in in FIGURE 2.

in many instances, that they are not solid and uniform in their structures, but seem to be aggregates whose composition of smaller particles can be frequently recognized. Different stages of the degree of packing can be observed. Some are more tightly held together than others. While some of the particles are larger than others, they may be, by themselves, composite in their nature (FIGURES 1, 5, and 6). A loose packing in the structure of the large particles would make their nonsedimentation more understandable. The more tightly packed aggregates could very well be pictured as having settled and become part of the pellet.

Dmochowski[5] believes, on the basis of his ultracentrifugation studies, that the Rous virus particle is much smaller than it is described in the literature, and he writes: "The activity of the supernatant fluids after high-speed centrifugation, may be attributed to the apparatus employed, to the different states of aggregation of the agents and to their dissociation into particles of smaller size which may require much greater centrifugal force for their sedimentation," Kahler *et al.*[3] consider that a varying degree of packing may be an explanation of their finding of values ranging from 1.175 to 1.12 of the densities of Rous virus. Gessler

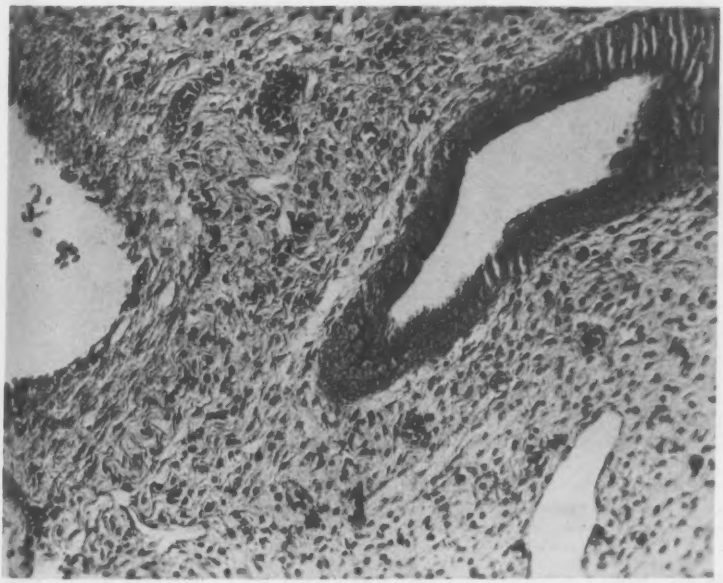


FIGURE 4. Section of a third-generation tumor grown in a fertilized chicken egg inoculated with supernatant of ultracentrifugate prepared from the tumor described in FIGURE 3. Note that the tumor cells are typical, although they are more compactly arranged. The nuclei are more plump, and there is less myxamatous change than is shown in FIGURES 2 and 3.

FIGURE 5. The top layer of an ultracentrifuged supernatant showing particles of 10 to 20 mμ diameters. Note larger particles showing distinct signs of being aggregates. Freeze-dried and shadowed at 10° angle. ×45,000.

et al.[2] show elementary and composite particles in electron micrographs of Rous virus sections.

Masses of particles of the level of 5 to 10 mμ diameters are portrayed in our electron micrographs and may be basic in nature. Unfortunately their dimensions are so close to the threshold of resolution of the elec-

tron microscope that no claim can be made as to their basic nature. That the active part of virus bodies are polynucleic acids with a protective coat of protein around them appears to be supported by sufficient evidence. Whether our efficient homogenization and protein elimination was able partly to accomplish a splitting and removal of some of the protein coating cannot be ascertained without meticulous chemical analysis. The fact remains, however, that, according to our electron micrographs, we seem to have been able to split off some of the material that had cemented the small particles into aggregates. Also, according to our assays, the virulence of the supernatant had materially increased when

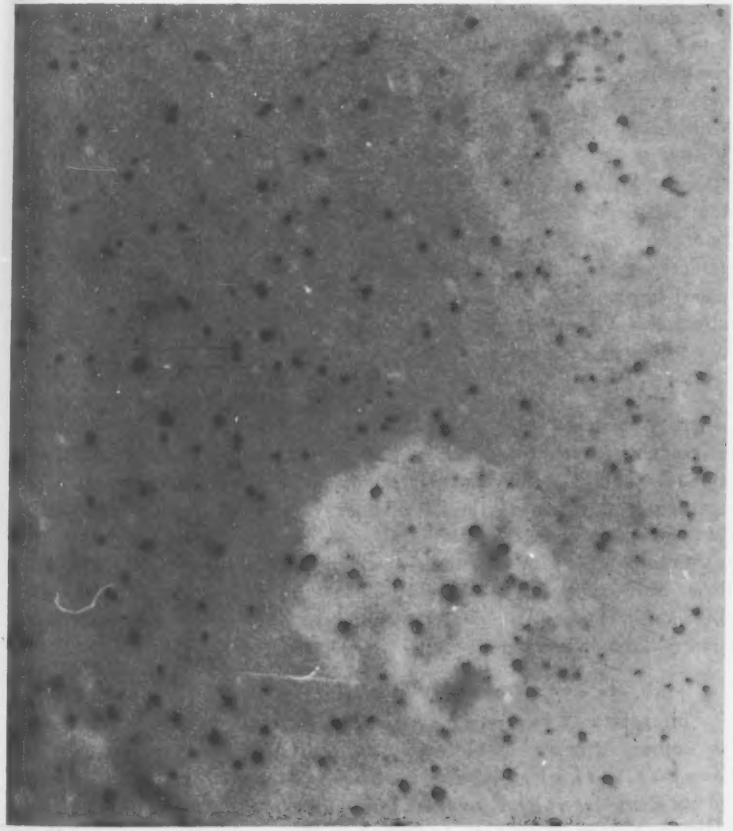


FIGURE 6. Ultracentrifuged supernatant showing dense spherical particles of 10 to 20 mμ. Note tendencies of particles to aggregate. Air-dried and not shadowed. ×45,000.

proteins, and possibly inhibitors, were removed from the viral material by our procedure.

Naturally, quantitative determinations of sedimentation figures and relating activity must be carried out in order to throw more light on this nonsedimentation phenomenon as observed by us. Equally so, protein, nucleic acid, and lipid determinations of the supernatant have to be made. Mention should be made that no trace of a top layer could be discerned after ultracentrifugation, which strengthens our belief that most or all lipid contents of the tissue are eliminated by the Freon-heptane treatment.

Experiments were made to verify the small dimensions of the agent by ultrafiltration through Parlodion filters possessing a maximum pore size of about 23 mμ. While it was found that the filtrate, when inoculated into eggs, had sufficient activity to produce some growth on the allantoic membranes, this activity began to recede after 3 to 5 days. Since this was in great contrast to the unfiltered material, the filter was tested with dilute solutions of colloidal gold possessing an average particle size of 9 mμ in diameter. When no trace of gold could be found in the filtrate by spectrographic analysis, it was evident that the particles were retained or adsorbed within the filtering structure. Maier and Bentelspacker,[6] and also Helmeke,[7] in their papers on the complicated microstructures of such filtering membranes, show evidence that particles, small in proportion to average pore size, are frequently held within the structures. Vernon Riley also describes the adsorption of Rous virus on diatomaceous earth.

Summary

A new method is described and discussed for the removal of nonviral proteins and lipids from viruses present in homogenates of virus-infected tissue. Vaccinia virus and Rous sarcoma virus were selected as representing 2 extremes in the dimensions of animal viruses. Stripped of accompanying nonactive materials and possible inhibitors, the viruses exhibited higher virulence than observed by us before. In the case of the Rous sarcoma agent, additional points were its very small dimensions of 5 to 10 mμ and its nonsedimentation in low-density aqueous media during ultracentrifugation.

Acknowledgments

For assistance in this work we wish to express our thanks particularly to Anthony Rottino of St. Vincent's Hospital of the City of New York, New York, N.Y., whose advice, especially in the histological examination of our Rous tumors, was invaluable to us. We are greatly indebted also to John J. Kelsch, Elisabeth J. Fraenkel, William Lightbourne, and Marie W. Hartmann of The Research Laboratories of Interchemical Corporation, New York, N. Y., for their valuable assistance.

References

1. HARKINS, W. D. 1952. The Physical Chemistry of Surface Films. : 41-49. Rheinhold. New York, N. Y.
2. GESSLER, A. E., K. S. MCCARTY & C. E. GREY. 1949. Elementary and composite submicroscopic bodies in neoplastic tissue. Exptl. Med. and Surg. 7: 269-282.
3. KAHLER, H., W. R. BRYAN, B. J. LLOYD, JR. & J. B. MALONEY. 1954. The density of the Rous sarcoma virus in sucrose solutions. J. Natl. Cancer Inst. 15: 331-336.
4. ALEXANDER, J. 1926. Colloid Chemistry. 1: 859. Chemical Catalog Co. New York, N. Y.
5. DMOCHOWSKI, L. 1948. Investigations on the properties of agents causing fowl tumors. J. Natl. Cancer Inst. 9: 65.
6. MAIER, K. H. & H. BEUTELSPACKER. 1954. Beitrage zur Kenntnis der Hohlraumsysteme von Membranfiltern. Kolloid-Z. 135: 10-28.
7. HELMEKE, J. G. 1954. Neue Erkenntnisse über den Aufbau von Membranfiltern. Kolloid-Z. 135: 29-43.

SECTION OF MATHEMATICS AND ENGINEERING

ATOMIC POWER: ITS PROSPECTS AND REALITIES*

By Theodore Baumeister

Columbia University, New York, N. Y.

This paper on the subject "Atomic Power: Its Prospects and Realities" is written from the viewpoint of a power engineer rather than from that of the physical scientist or that of the practical businessman. This approach draws upon personal professional experience over the years in the area of power engineering in both the transportation and stationary fields but, more particularly, the stationary field. The design, selection, construction, operation, and economics of power plants for public utility systems and for industrial manufacturing establishments have been the major concern. This activity, in an engineer, calls for a balance between the scientific and the economic aspects of the alternative methods of generating power. There must be a clear recognition of (1) the scientific principles and potentials of power generation, and (2) the ever-present demands for reliable, economic, propriety to the service conditions. The power engineer must be cognizant at all times of this twofold purpose of his activity. He must at all times hunt with a double-barreled shotgun—one the science barrel and the other the economics barrel. It is this combination that leads to the true engineering approach, and the power engineer must clearly recognize both aspects or he will miss the target. Either he will violate basic dictates of science or he will choose a design that is inferior on the practical grounds of reliability, suitability, or cost.

Before investigating significant details in this atomic-power field it would be well to look briefly at the requirements for energy and fuels, both at present and in the foreseeable future. This will serve to develop a proper perspective. TABLE 1 shows a recent estimate of the energy consumption of the United States and of the world on a per capita basis. The consumption is allocated to 2 categories: (1) food, and (2) heat and power. These magnitudes are worthy of careful consideration. If the other parts of the world are to attain the industrial development that the United States has now attained, it will be necessary for them to increase their energy consumption fortyfold, on the average. This reflects the potential demand for energy in the future. The American civilization, however, is far from static, and many estimates made by reliable investigators predict a future demand of staggering magnitude. For example, the growth of the electric-power industry is now so rapid that within approximately 10 years it is expected that the size of the installed plant will have doubled. To appreciate this growth more strikingly

*This paper, illustrated with lantern slides, was presented at a meeting of the Section on May 18, 1956.

is to understand that it means that during the period from 1882, when Edison built the first electric-power station at Pearl Street in New York, N.Y., until 1956, the net installed capacity has grown to more than 100 million kw. By 1965 the nation will have to install new additional capacity of more than 100 million kw. This is growth at a fantastic rate even for the most highly industrialized nation on earth.

These anticipated demands for heat and power not only dwarf those of all other national economies but they pose the much more significant question "from what source will the raw energy come?" These requirements will be met in the immediate future by tapping the same sources that have heretofore prevailed. Reliance will be placed upon the fossil fuels—petroleum, natural gas, and coal. Water power will supply some of the needs but in ever-decreasing percentages of the total. The Congo River watershed offers a potentiality that eclipses anything in the hydro power area of the Western Hemisphere. The American people, however, seem to wish to work and live in the United States rather than in the African tropics. Even in the United States the large remaining undeveloped hydro area is the Pacific northwest. That potential, even with the marvels of high-tension electric transmission, would be of little help to the industrial northeastern and north-central parts of the nation. It is likewise of no interest to most transportation power plants. Fossil fuels are the main source of reliance in the United States, where we burn coal and oil and gas to give an ever-increasing fraction of the 500,000 B.t.u. per day, an amount that is increasing daily and is needed by every American to keep the national economy functioning. This demand on our fossil-fuel resources is reflected in the repeated warnings that we are faced with imminent depletion of our petroleum supplies. Nature has simply not given us an inexhaustible supply, but the oil industry, the petroleum geologist, and their associates have done a remarkable job in keeping abreast of the demands. The coal fields have been doing a tremendous job in providing the raw material for electric power—100 million tons of coal were consumed by utilities in the United States in 1950, 143 million tons in 1955. The Tennessee Valley Authority has increased its coal consumption many fold since World War II. Today the TVA is the nation's largest coal buyer. Such demands for our conventional fuels

TABLE 1

ESTIMATED DAILY ENERGY-CONSUMPTION FIGURES

B.t.u. per Capita

	For food	*For heat and power*
United States	12,000	500,000
The world	10,000	25,000

cannot be continued, or stepped up, except by drastic changes in various directions. The demands for fossil fuels are very optimistic, but the likely supplies are not all that we could desire.

One direction for meeting this energy demand that is most attractive, and that will not be denied, is toward nuclear fuels. Exact data on reserves and resources are not available. The dictates of secrecy and the novelty of the nuclear field combine to give information that is conjectural. The striking element in that conjecture, however, shows an expanding reserve that was undreamed of even 10 years ago. The reserves of uranium and thorium alone have been stated to run approximately 2 dozen times the magnitude of all the conventional fuel reserves in the world. There are many experienced people who say that this multiplier of 22 is low, ridiculously low (see TABLE 2). It is not within the province of this paper to explore the size of this figure. It is sufficient for any practical power engineer to know that if he builds plants for burning nuclear fuels he will be able to count on reserves that make his conventional fuel reserves look almost irrelevant. Industry, moreover, has not slackened its pace in building plants that will burn coal, oil, or gas. Therefore, if practical, reliable nuclear power plants can be developed to solve the fossil-fuel problem, the problem of continuing the supply of fuel disappears from consideration.

In an effort to show broadly the various categories of power-plant applications and to help in the identification of those categories where the nuclear plant can expect to find particular suitability, TABLE 3 has been prepared. This table contains approximate estimated values of the installed capacity of American power plants. A high degree of accuracy in the preparation of such data is not justifiable because of the wide deviations in the definition of a horsepower or a kilowatt. This is not the place in which to elaborate on these deviations, but it should suffice for the purpose to cite the difference in the practical meaning of a

TABLE 2

ESTIMATED WORLD RESERVES OF FUEL ENERGY

Fuel	*Energy, B.t.u.*
Fossil fuels	
Petroleum	$< 8 \times 10^{18}$
Natural gas	$< 1 \times 10^{18}$
Coal	72×10^{18}
Total fossil fuels	80×10^{18}
Fission fuels (1-to-1 breeding)	1770×10^{18}

Ratio of fission to fossil fuels is 22 to 1.

TABLE 3

APPROXIMATE (ESTIMATED) INSTALLED CAPACITY OF POWER PLANTS OF THE UNITED STATES

	Millions of kw.
Public utility central stations	120
Industrial	30
Agricultural	50
Railroad	90
Military establishment	1000
Automotive	5000
Other	60
TOTAL	6350

horsepower as applied to a seagoing merchant ship, on the one hand, and to a passenger automobile on the other. From the viewpoint of any analysis of power requirements in the American industrial economy, the tabular data reflect such significant items as:

(1) The transportation-field plant capacity outranks all other plant capacities.

(2) The number of individual, self-contained units in the transportation field is literally thousands of times larger than in the stationary field. In addition, the dominant size of the unit in the transportation area is much smaller than in the stationary group, with the 60 million automobiles and their 100 to 200 hp. size as typical.

(3) The overwhelming magnitude of the plants that use the raw energy of fuel is represented in 100 per cent of the transportation plants and not much less than 100 per cent of the stationary plants.

It is informative to reflect on such figures because they serve to show broadly the competitive situation into which the nuclear plant must plunge if it is to annex its proper share of the field. The competition stems from the fossil-fuel-burning plant. The hydro field is of small significance. In fact, George Graham Brown[1] in January 1956 summed up the situation on hydroelectric power generation in the statement "Hydro power is a small contributor, about 1/2 of 1% of the total energy requirements of the world, and is past its period of maximum rate of growth." Or, put more strikingly, "The burning of dung is a larger contributor to the world's energy than water power—ten times as large."

The broad field of power-plant applications is thus briefly defined. It is in this competitive situation that the nuclear plant must find its level. It is rational, therefore, to study the many categories in an effort to determine which areas are peculiarly suitable for nuclear applications. It is hardly reasonable to suppose that all fields will be equally accessible. The competition will be very severe, and it is probable that

the nuclear plant will be confined to certain sharply recognizable areas. In each area the competition will be with the most modern, the most highly developed, equipment—not with the older or average types. There will be no one best nuclear power plant, anymore than there can be one best fuel-burning power plant that can supply all services and meet all criteria to the exclusion of all other plants or designs. Many criteria must be meticulously studied and evaluated to determine which plant or type of plant is best suited to meet the service requirements. These criteria would variously include items such as reliability, flexibility, reversibility, weight, life, investment, and operating cost. A comparison of stationary steam plants, hydro plants, automobile engines, sea going ship plants, aircraft engines, and railroad locomotives on these several criteria will show widely divergent answers. For example: (1) hydraulic turbines show maximum reliability, with lack of water often the biggest obstacle to continuity of service; (2) central-station steam turbines will operate 50,000 hours (5 or 6 years) without need for opening the casing; (3) passenger automobiles perhaps average 3,000 hours of operating life; (4) aircraft gas turbines may weigh 0.1 lb. per hp., but marine power plants could range to 100 or 200 lbs. per hp.; (5) hydro plants can be brought on the line in a matter of minutes, but modern reheat steam plants require hours for starting; (6) a steam central station will use 10 to 20 ft.^{3} per kw. for housing, while an automobile power plant would use but a very small fraction of that space; (7) a pound of uranium contains the energy equivalent of 1,300 tons of coal or 250,000 gal. of fuel oil; and (8) coal costs 30 to 40¢ per million B.t.u. in the New York area, but gasoline costs more than $2 per million B.t.u. These are a random selection of some of the divergent figures that can be found in the potentially competitive criteria that must be considered in the evaluation of a power plant.

In any effort to perfect a nuclear power plant that will meet the various judgment criteria on propriety, problems that fall into 3 readily identifiable classes will be distinguishable: (1) legal, (2) technical, and (3) economic. It seems inappropriate in this paper to spend any great time on the legal phases of nuclear energy. Suffice it to say that unprecedented problems are presented here because, under the law, only the federal government can own nuclear fuels. Hence, whenever an atomic power plant is projected there is only one legal source of fuel supply. This is unique in a free-enterprise economy. Similarly there are problems of disposal of plant wastes, of the transportation of fission fuels, of patent rights, and of the liabilities that would attend an atomic accident or explosion. Many solutions have been suggested for these and similar problems, but even the best legal minds have not devised practical compensatory arrangements that will protect both the user of nuclear fuels and the nonuser or general public who owns the fuel through the government and who might be damaged by unforeseen or unforeseeable hazards

in the manipulation of nuclear apparatus. As scientists and technologists, it is essential to recognize that nuclear power plants must be built and run within this realistic legal framework. It is a framework that has been developed, at best, only in skeletal form. It is there, however, in all its stark reality.

The technical problems, on the other hand, are such that many engineers and scientists can make contributions that will lead to better designs of nuclear plants. The many combinations of component variables in the design of reactors offer a field day for the inventive mind. Such elements as fuels, breeding, blankets, moderators, coolants, and structural materials all combine to give a wide assortment of heterogeneous or homogeneous reactor possibilities. Each can show some merits, but each has its accompanying disadvantages. These factors have all to be weighed, compared, and evaluated with the hope that a plant will result that will offer genuine competition for conventional equipment when viewed in the light of the several criteria already cited.

An application of the fundamental thermodynamics of the Carnot cycle to nuclear reactions shows startling results. The temperature of the reaction ranges to millions of degrees, so that with a thermodynamic atmospheric sink temperature of 500° R. the thermal efficiency (th. eff.) of the ideal Carnot cycle would be

$$\text{Th. eff. nuclear fuel-fired plant} = \frac{1{,}000{,}000 - 500}{1{,}000{,}000} = \frac{999{,}500}{1{,}000{,}000} = 99.95 \text{ per cent}$$

This compares with the ideal efficiency when burning conventional fuels and with furnace temperatures of the order of 2500° F. or 3000° R.

$$\text{Th. eff. conventional fuel-fired plant} = \frac{3000 - 500}{3000} = \frac{2500}{3000} = 83.33 \text{ per cent}$$

Power engineers are accustomed to deal with heat rates rather than thermal efficiency for the more convenient direct evaluation of fuel consumption. Heat rate is defined as the heat energy that must be supplied in fuel to deliver 1 kilowatt-hour (kw.-hr.) or horsepower-hour (hp.-hr.) of output at the power plant terminals. As a kilowatt hour is the mechanical equivalent of 3412.75 B.t.u., the above thermal efficiencies become

$$\text{Carnot cycle, nuclear fuel-fired plant} = \frac{3{,}412.75}{0.9995} = 3{,}415 \text{ B.t.u. per kw.-hr.}$$

$$\text{Carnot cycle, conventional fuel-fired plant} = \frac{3{,}412.75}{0.8333} = 4{,}095 \text{ B.t.u. per kw.-hr.}$$

The heat consumption of real power plants is much higher than these figures, and some typical values are shown in TABLE 4. The significant

observation to be made from these facts is that the nuclear plant, by virtue of its high heat-source temperature, offers, thermodynamically, the potential of the best heat rates for any type of power plant that can be visualized.

This high intrinsic thermodynamic efficiency must, of course, be compromised when an attempt is made to harness the heat of nuclear reactions to the turning of the wheels on an actual prime mover that meets the practical criteria previously given. From among the almost limitless number of possible realistic cycles that can be postulated, the power engineer finds himself confined to a very few satisfactory arrangements. These arrangements call for the use, today, of (1) a gas-turbine type of plant, or (2) a steam-turbine type of plant. Other proposals are so conjectural as to receive scant consideration, at this time, by any power engineer worthy of the name. In fact, the realistic thinking is so limited that all nuclear plants built or under construction are using steam as the thermodynamic fluid. This means that nuclear power plants, today, substitute a nuclear reactor for a coal-, oil-, or gas-fired furnace. The heat released in the reactor or furnace is used to generate steam at an elevated pressure and temperature. The steam so generated in a boiler is then led to a turbine, condenser, feed pump, feed heater cycle which uses equipment that does not change with the source of heat. Many plans are afoot to substitute a fixed gas for steam in the thermodynamic cycle and thus lead to a gas-turbine plant. This plan has merit because it should simplify the equipment by eliminating the steam boiler, the condenser, the feed heaters, and the water-treatment items, among others. Such construction should reduce weight, bulk, and investment, and should improve reliability and flexibility. A consideration of the thermodynamics, however, discloses some of the vital road blocks that will have to be removed before the gas-turbine equipment is acceptable in nuclear applications.

TABLE 4

REPRESENTATIVE THERMAL PERFORMANCE OF SOME SELECTED FUEL-BURNING POWER PLANTS

Type of plant	*B.t.u. per kw.-hr.*
Average central station steam plant	12,000
Best central station steam plant	9,000
By-product, industrial steam plant	5,000
Diesel plant	11,000
Simple gas-turbine plant	20,000
Steam locomotive	60,000
Diesel-electric locomotive	15,000

For gas turbines the Brayton cycle is basic. The ideal heat rate improves rapidly as the ratio of compression is raised, as shown in the expression for efficiency

$$\text{Th. eff., ideal Brayton cycle} = 1 - \frac{1}{R^{k-1}}$$

where R = volumetric ratio of compression

k = ratio of specific heats of the gas at constant pressure and volume

Thus, with a compression ratio of 3, the efficiency is 35 per cent and, with a ratio of 6, the efficiency is 51 per cent when using air as the working fluid.

The adaptation of realistic mechanism to the gas-turbine cycle introduces some serious elements of deviation from the ideal standards. The gas-turbine power plant, as it is customarily constructed today, embraces (1) a compressor, of the axial-flow type; (2) a heater in which the gas is raised to an elevated temperature; and (3) an expander in which the hot gases drop back substantially to the original pressure. The work delivered by the expander is greater than that required by the compressor. The difference between these 2 values of work represents the net output of the plant and can be used to drive an electric generator, a pump, a ship's screw, an airscrew, or the difference can be used as a propulsive jet. This can be expressed algebraically as

$$\text{Ideal net work of gas-turbine plant} = W_{exp.} - W_{compr.}$$

where $W_{exp.}$ = work output of expander

$W_{compr.}$ = work input to compressor

For a given-size compressor, working between specified pressures on a specified gas, it is possible to increase the net output by raising the temperature of the fluid entering the expander and thus raising $W_{exp.}$ If, further, the compression efficiency, e_c, and the engine efficiency, e_e, are introduced to allow for deviations from perfection, which must occur in all real machinery, the net work of the plant becomes

$$\text{Actual net work of gas-turbine plant} = W_{exp.} \times e_e - \frac{W_{compr.}}{e_c}$$

These mechanism efficiencies, e_e and e_c, are of controlling significance, as can be demonstrated by a simple substitution, as follows, for a case where, with an acceptable maximum initial temperature entering the expander, the values might be $W_{exp.}$ = 10,000 hp. and $W_{compr.}$ = 5000 hp. The results of substitution in the equations for net output become those shown in TABLE 5 for several mechanism efficiencies. Such calculations and results demonstrate strikingly the need for (1) high mechanism ef-

ficiency, and (2) high fluid temperatures at the expander throttle if a gas-turbine power plant is to be made a practical economic device. This means temperatures that today are higher than can be obtained with any realistic reactor. With development in the art, however, higher temperatures should be possible and, as those temperatures reach into the region of 1200° to 1500° F., the gas-turbine plant will have to be given consideration. The key to this problem is temperature, and efforts must be directed toward its elevation.

It is this temperature item that makes the power engineer turn toward the steam cycle as a practical device for the use of reactor heat in the driving of prime movers. If the latent-heat effect of steam can be utilized, the thermodynamic possibilities are greatly improved. Thus in a steam system where the steam temperature is 545° F. (1005° R.), and the atmospheric (sink) temperature is 80° F. (540° R.) the thermal efficiency of the Carnot cycle would be

$$\frac{1005 - 540}{1005} = \frac{465}{1005} = 46.3 \text{ per cent}$$

The Rankine cycle, which is more realistic when dealing with steam plants, would give, with dry saturated steam, an efficiency somewhat less (38.5 per cent). For the temperatures postulated, the steam pressure would be 1000 p.s.i. and the exhaust pressure 0.5 p.s.i.a. A plant operating under these conditions would give a very acceptable performance as judged by modern standards. A rudimentary steam plant contains 4 significant elements: (1) a boiler to generate steam, (2) a prime mover (turbine or engine), (3) a condenser, and (4) a feed pump. The net output of the assembled plant is, like that of the gas-turbine plant, the difference between the power delivered by the prime mover (W_{pm}) and the power required to drive the pump (W_p) or

$$\text{Actual net output of steam power plant} = W_{pm} \times e_{pm} - \frac{W_{pump}}{e_p}$$

where e_{pm} = engine efficiency of the prime mover

e_p = pump efficiency

TABLE 6 shows the consequence of substituting values of work and efficiency in this expression. For example, basic data of 10,000 hp. for the ideal prime mover and 66 hp. for the ideal feed pump have been used. When realistic efficiencies are introduced, the reduction in usable, salable, net output leads to totally different conclusions than for the gas-turbine plant of TABLE 5. The minor significance of the feed-pump requirements, as contrasted with the compressor requirements of the gas-turbine plant, is the key to the great merit of the steam system. Further, such acceptable performance does not call for temperatures in the region of 1000° F. to 1500° F. but can be accomplished with much lower tem-

TABLE 5

CHANGE IN NET OUTPUT OF A SELECTED GAS-TURBINE PLANT WITH CHANGE IN MECHANISM EFFICIENCY

Case	*Compression and engine efficiencies, per cent*	*Horsepower*		
		Expander	*Compressor*	*Net for plant*
1 (base)	100	10,000	5,000	5,000
2	90	9,000	5,560	3,440
3	80	8,000	6,250	1,750
4	70	7,000	7,140	−140

peratures, namely, 500° F. to 1000° F. This serves to substantiate the overwhelming preference in all nuclear power plants, now building or in operation, for the use of steam as the thermodynamic fluid. Reactor temperatures are kept low, comparatively. A coolant that may be liquid metal, gas, water, or steam itself, can be used to bring the heat from the reactor to a heat exchanger, and/or to the turbine. Heat-transfer, fluid-dynamic, operating-control, metallurgical, and radioactivity considerations lead to a wide assortment of proposed methods of adapting the raw heat energy of the reactor to the preparation of steam for the prime mover.

This is briefly the basic technical background material for the present status of the nuclear power field and its preference for the steam cycle. It is rational, of course, to expect that the extensive efforts being made by research, development, and operating groups will bring many and rapid changes. The perfection of new metals suitable for nuclear service and of the design and fabrication of fuel elements are obvious steps in the desired direction. It may be that the efforts to substitute ceramic materials for metals will lead to higher operating reactor temperatures. These could conceivably avoid very high operating pressures, such as those prevailing with the pressurized water reactors. Gases under moderate pressures might be substituted for the direct cooling of the reactor and for thermodynamic purposes, thus avoiding the complexity of intermediate coolant fluids and loops and their attendant bulk and cost. As a power engineer working in the field of commercial reality, however, the author is impressed with the dominant position of the pressurized water reactor, and he must emphasize those technical limitations and advantages that dictate the thinking in the present state of the art.

Any commercial power plant has to face the realities of cost and be acceptable in economic competition with other methods of providing the same power service. Many scientists and technologists are frequently and humanly inclined to forget the all-pervading importance of the

economic picture. Many of the rules that govern economics are man-made, so there will be different interpretations and alterations of previous interpretations. The basic rules that are to be employed are consequently subject to deviation and definition. For example, the complete monopoly, under law, of fissionable fuel ownership in itself introduces governmental accounting and cost-computing methods and values instead of those employed by industry. Coal mines and oil fields are run by private enterprise, but nuclear fuels are recovered only under government supervision and regulation. Items such as property taxes, income taxes, depreciation, return on debt or equity capital, and insurance simply are not charged in the same way or in the same amounts for governmental, as opposed to industrial enterprises. Hence when economics and costs are to be compared it is essential to recognize the differences in underlying philosophy and cost that must prevail. These differences make it exceedingly treacherous to attempt to judge the economic worth of nuclear power. As a prelude to any estimate of nuclear power costs, TABLE 7 has been prepared to show the range of generating costs as they might prevail in investor-owned, business-managed, modern, steam-electric, utility power plants for the northeastern section of the United States. These costs, which range from 4 to 8 mills per kw.-hr., should be contrasted with those given in TABLE 8 for the first nuclear steam-electric station in the United States, at Shippingport, Pa. These latter costs are admittedly for a pioneering activity and cannot be compared with those for well-established practice as recorded in TABLE 7. They do serve to put a dollar sign on nuclear power costs, however, and they indicate the large strides that remain to be taken if nuclear power is to annex its share of central station electric generation.

A further step in the economic comparison for commercial electric power production requires the recognition that the power plant is only one part of the entire electric system that serves to take raw energy from fuel and to deliver it as a finished product (kw.-hrs.) to the customer at his point of use. Transmission and distribution thus add substantially to

TABLE 6

CHANGE IN NET OUTPUT OF A SELECTED STEAM PLANT WITH CHANGE IN MECHANISM EFFICIENCY

Case	*Pump and engine efficiencies, per cent*	*Horsepower*		
		Turbine	*Pump*	*Net for plant*
1 (base)	100	10,000	66	9,934
2	90	9,000	73	8,927
3	80	8,000	83	7,917
4	70	7,000	95	6,905

TABLE 7

REPRESENTATIVE COSTS OF GENERATING ELECTRIC ENERGY IN MODERN FUEL-BURNING POWER PLANTS IN THE NORTHEASTERN PART OF THE UNITED STATES

	Cost in mills per kw.-hr.		
	Low	*Intermediate*	*High*
Fixed charges on investment	2.0	3.0	4.0
Fuel cost	1.5	2.5	3.5
Labor and maintenance	0.5	0.5	0.5
TOTAL	4.0	6.0	8.0

generating costs. A modern steam-electric utility power plant might cost $150 per kw., but the transmission and distribution plant could easily raise the price to $450 per kw. when judged by investment from fuel pile to the power customer's meter. If a nuclear plant is considered as an alternative to a conventional fuel-fired power plant, all of the transmission and distribution-facilities investment ($300 per kw.) would remain unchanged. Similarly, within the powerhouse itself and using the steam system for the technical reasons outlined above, the investment for turbines, generators, condensers, structures, and electrical switchyards and busses, would remain substantially unaltered. In fact, the boiler room and fuel-burning part of the plant is all that would be changed drastically in going from a fossil fuel- to a nuclear fuel-fired plant. This might constitute one half of the power-house investment, or $75 per kw. Or, put another way, five sixths of the system investment cannot be changed by substituting nuclear fuel for conventional fuel. The only item subject to possible manipulation is $75 per kw. or one sixth of the total investment. This places a severe economic burden on the nuclear project.

Such considerations as these lead many people to believe that the era of nuclear electric power systems for stationary services is not imminent for this part of the world. Regions that lack fossil-fuel reserves, or in which fuel prices are high, offer a more fertile area for cultivation of the nuclear power idea. The prospects are also enhanced when large-capacity plants are acceptable rather than small plants. Such areas are not numerous by reason of the fact that large users of power have not generally sought areas that were not blessed with adequate raw energy reserves—either fossil fuels or falling water.

Beyond the stationary field there are plenty of areas where the nuclear power plant will doubtless find great favor. Transportation plants calling for large power outputs, or using high-priced fuels, or fuels in large quantities, or for high-speed propulsion are typically attractive for nuclear applications. This does not embrace services such as automobiles, motor boats, tractors, or locomotives, but it most certainly must include

seagoing ships and modern large airplanes. Aircraft service, calling for power plants of 50,000 hp. capacity, burn over 10 tons an hour of high-priced liquid fuel. Such weights alone make it attractive to consider the weightless nuclear fuels. Even the extensive protective radioactivity shielding cannot offer a serious deterrent in the powering of large long-range aircraft.

Similarly, in the propulsive plants for ships, especially naval vessels, there is no choice other than to use nuclear fuels for navies of the future. When it is recalled that power requirements go up as the cube of the speed, any attempt to raise the speed of capital ships leaves no alternative to nuclear power. In military service, there is no substitute for speed, and the ships of the future will demand ever-increasing power-plant capacities. The cube relationship cited poses an impossible problem with conventional fuels. The size of the boilers and of the bunkers is a prohibitive factor. If the speed were to be doubled the plant size and fuel consumption would go up eightfold. Of course this speed requirement is not the only element that lends great favor to the choice of the nuclear plant. The world-wide availability of fuel, the operating radius of the ship, the refueling facilities, and the possible adaptation or conversion of existing seagoing plants are likewise all significant factors in the powering of ships. This situation is made to order for the weightless nuclear fuel. When adapted to military necessity there can be no price tag. The costs in dollars in warfare must give way to the demands for maximum military effectiveness. It is on these grounds that many of the best engineering minds in the United States Navy have been projecting a fleet within 10 years that must be nuclear-propelled. The fleet, otherwise, will be obsolete. Submarines propelled by nuclear fuel are already realities, and other ships are fast reaching the same stage. Lessons of inestimable value will be learned here on the design,

TABLE 8

EXPECTED COSTS OF POWER FROM THE FIRST NUCLEAR ELECTRIC POWER PLANT AT SHIPPINGPORT, PA.

Case A — First estimate with conservative allowances	52 mills per kw.-hr.
Case B — First estimate with optimistic allowances	39 mills per kw.-hr.
Case C — Duplicate plant of the future, to be built after gaining operating experience on the first one, which is not yet in service	14 mills per kw.-hr.

Note: The total cost of electric energy for several other projected nuclear plants in the northeastern United States is expected to eclipse 10 mills per kw.-hr.

construction, and operation of nuclear power plants. These lessons will have far-reaching effects, not the least of which will be in perfecting reliable nuclear power plants for commercial services, and in situations where the price tag will dominate the ultimate selection. The cost of warfare is horrible to contemplate, but the development of nuclear power plants for military applications is one small compensatory element that will help to further the peacetime uses of nuclear energy. In this way there will at least be some benefits that can lead to progress in the best interests of all mankind.

Reference

BROWN, G. G. 1956. Thinking ahead: nuclear and solar energy. Harvard Bus. Rev. 34: 17.

*SECTION OF OCEANOGRAPHY AND METEOROLOGY**

RIVER AND WATER-SUPPLY FORECASTING**

By Max A. Kohler

United States Weather Bureau, Washington, D. C.

Introduction

For many years the river forecasting service of the United States Weather Bureau was confined principally to the larger, more sluggish streams where reasonably accurate forecasts could be made by rules of thumb. Today forecasts and warnings are issued for more than 1000 localities over the nation, including many headwater points with less than 100 square miles of drainage area. The forecasts are now initially based on reported amounts of rainfall and related meteorological and hydrologic factors. After flood waters have collected in headwater channels, reported river stages provide the means for issuing revised or confirming forecasts. Except in extreme headwaters, forecasts are made of the entire hydrograph, that is, the time graph of stage or discharge at a point.

River Forecasting Methods

The flood hydrograph is synthesized in 2 steps. First, an estimate is made of the volume of water that will run off the contributing area and, second, this runoff volume is distributed through time.

Rainfall-runoff relations. For the purpose of forecasting, runoff is assumed to fall into 2 classes: (1) base, or groundwater flow; and (2) direct runoff. The method of hydrograph separation used by the Weather Bureau is shown in FIGURE 1. The curve *AB* represents an extension of the recession existing prior to the storm, point *B* being directly under the peak. The straight line *BC* intersects the hydrograph at a point *n* days after the crest or after the end of runoff-producing rainfall. Although the value of *n* applicable to a particular basin is a complex function of area, slope, and other factors, it is normally estimated subjectively. The volume represented by the area bounded by the hydrograph and *ABC*, converted to inches of depth over the basin, is considered to be the storm runoff.

The quantity of runoff resulting from a storm is a function of the moisture deficiency of the basin at the beginning of rainfall and of the storm characteristics such as rainfall amount, intensity, and duration. While the storm characteristics can be determined from an adequate network of reporting precipitation stations, the direct determination of

*The Section of Psychology held a meeting on May 21, 1956, at which a paper "Problems in the Ontogenetic Background of Adaptive Behavior and Emotion" was presented by T. C. Schneirla of the American Museum of Natural History, New York, N. Y. This paper will be published in a later edition of *The Transactions*.

**This paper was presented at a meeting of the Section on May 22, 1956.

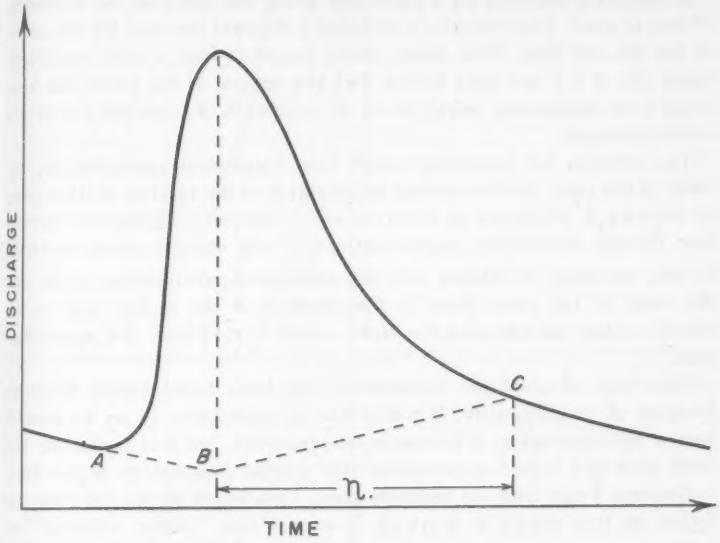


FIGURE 1. Method of hydrograph separation.

moisture conditions throughout a basin is extremely difficult. Reliable point observations of soil moisture are possible, but variations in soil type, crop cover, and antecedent conditions make adequate sampling excessively expensive. Moreover, any complete moisture accountability must include consideration of conditions on and above the soil surface, since the quantity of water that can be stored in surface depressions and intercepted by vegetation must be supplied at the expense of runoff. The complex nature of river basins thus precludes the direct physical or analytical approach to the determination of runoff. Instead, empirical relations are developed through statistical analyses of the measurable factors directly related to runoff phenomena.

In the runoff relations currently being used by the Weather Bureau,[1] a weighted value of antecedent precipitation is used in connection with the season of the year to reflect the moisture deficiency of a basin. The manner of computing this moisture index is illustrated in FIGURE 2. The broken line is a plotting of the index versus time, and the bars represent rainfall. This technique assumes that the rate of evapotranspiration at any time is proportional to the quantity of moisture available, which is equivalent to stating that the quantity of moisture stored within the basin recedes exponentially with time during rainless periods. Thus the index for 1 day is equal to that of the previous day multiplied by a factor *K*. If rain occurs on any day, the amount of rain observed is added to the index.

In compiling the data for a particular storm, the index at the beginning of rain is used. For example, a value of 1.8 would be used for the storm of the 9th and 10th. This index, when computed from a daily recession factor (K) of 0.9 and used jointly with the season of the year, has been found to be reasonably sensitive as an indication of moisture conditions within the basin.

The relation for predicting runoff from antecedent precipitation, the week of the year, and the amount and duration of the rainfall is illustrated in FIGURE 3. Relations of this type are developed by graphical correlation through successive approximations of the various curve families. In use, the chart is entered with the antecedent precipitation index and the week of the year; down to the duration of the storm; over to the amount of the rainfall; and the storm runoff is read from the appropriate axis.

This type of graphical correlation[2] has been found highly effective because of its flexibility. It would not be practicable to try to present here a full discussion of the technique involved, but this technique has such wide and varied applications that a brief description is justified.

FIGURE 4 clarifies the methods used. This figure shows the same relation as that shown in FIGURE 3, except that "basin recharge" re-

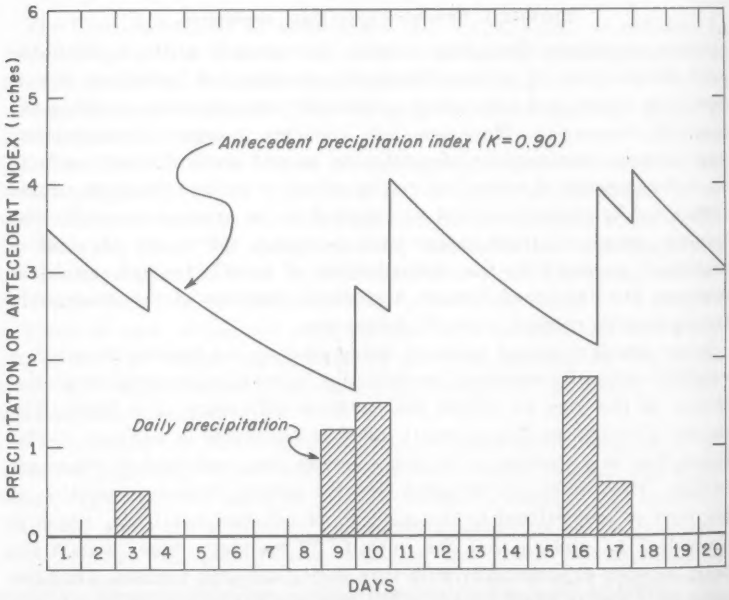


FIGURE 2. Variation of antecedent index with daily precipitation.

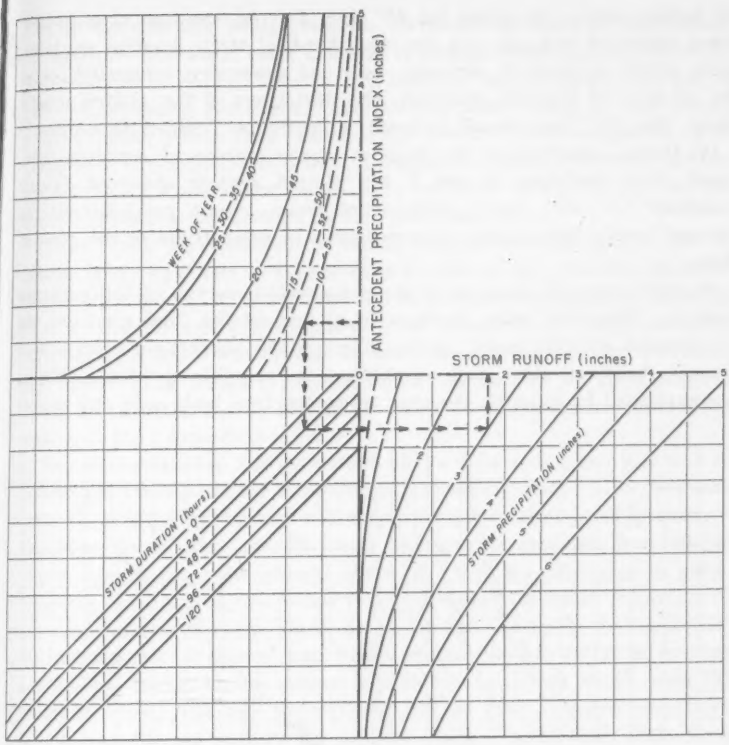


FIGURE 3. The runoff relation for the Monocacy River at Jug Bridge, Md.

places runoff as the dependent variable. Recharge is defined as that portion of precipitation that does not run off into the stream channels, that is, precipitation minus storm runoff. The relation shown in FIGURE 4 is derived as follows:

(1) Values of recharge are plotted against corresponding values of the antecedent precipitation index, and the points are labeled with "week of the year" (quadrant *A*). Only those storms falling within a selected rainfall range are plotted at this stage of the analysis.

(2) Contour lines are then constructed to fit the plotted values of the parameter. The relation in this quadrant provides a means of estimating recharge from the antecedent precipitation index and from the week of the year.

(3) Observed values of recharge are then plotted against those values computed from the first quadrant, and the points are labeled with "storm duration" (quadrant *B*). If the relation of the first quadrant were exact,

all points would plot along the 45° line, that is, the line of computed equal observed recharge. On the other hand, if storm duration explains some of the variation in recharge, over and above that accounted for in the relation of the first quadrant, the deviations of the plotted points about this 45° line should indicate a family of "correction curves."

(4) Having constructed the duration curves, values of recharge computed from quadrants *A* and *B* are plotted against observed values (quadrant *C*). The fourth independent factor, storm precipitation, is entered beside each point. A curve family is again fitted to the plotted data.

At this point we have the first approximation curves of the recharge relation. Since the curve families in all except the final quadrant are constructed without regard for the effect of the subsequent independent factors, however, they must be checked for possible revision. This is accomplished by entering the chart sequence from both ends and replot-

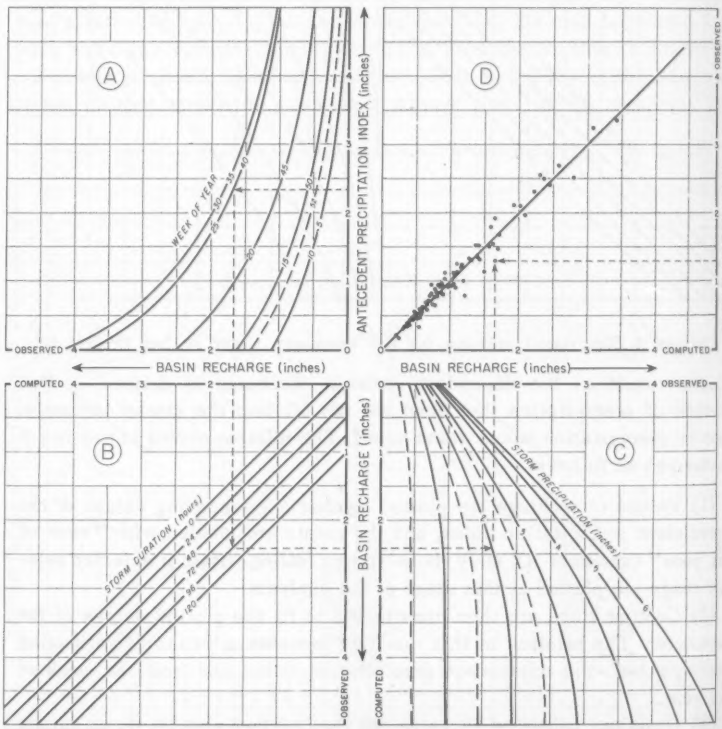


FIGURE 4. The basin recharge relation for the Monocacy River at Jug Bridge, Md.

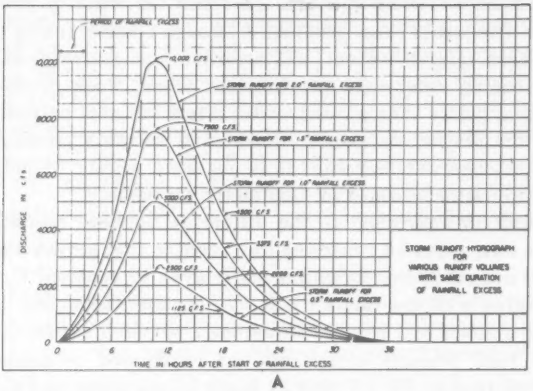
ting in the quadrant being checked. To check the week of year curves, for example, one would enter quadrant *A* through *C* and *B* (using observed recharge, storm rainfall amount, and duration, successively) and plot at the corresponding antecedent precipitation index. Week of year curves exactly fitting points thus plotted would result in exact estimates of recharge for the respective storms. Quadrant *D* shows a plotting of computed versus observed recharge. It is included merely to indicate the degree of correlation attained for this particular basin.

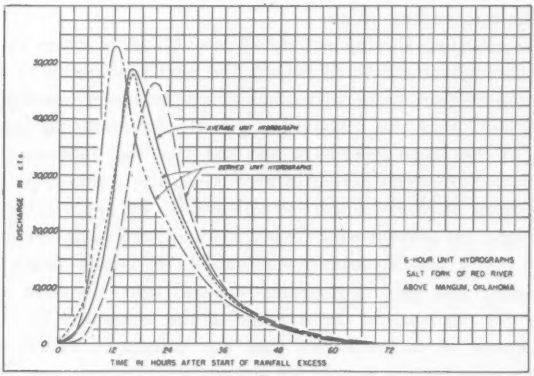
Since runoff is equivalent to the difference between rainfall and recharge, FIGURE 4 can be converted to a relation that provides estimates of runoff (FIGURE 3) by reorienting the curves in quadrant *C*. Entering such a relation with the rainfall that has occurred up to any particular time during a storm will provide an estimate of runoff for that portion of the storm. Thus 6-hourly increments can be derived by computing the runoff for the first 6, 12, 18, and 24 hours of the storm and subtracting each from the succeeding value.

Runoff distribution. Having estimated the volume of water that will be discharged throughout the flood period, the next problem is to determine the rate at which this water will reach the point under consideration. It has been found[3] that the discharge hydrographs resulting from similar storms are of the same general shape and that the discharge at corresponding times during the period is approximately in direct proportion to the total volume of storm runoff (FIGURE 5A). To apply this principle, the hydrographs for several past floods are analyzed to derive an average hydrograph for a runoff volume equivalent to 1-inch depth over the drainage basin. The unit hydrographs derived from 3 storms are shown in FIGURE 5B, as well as the average of the 3 graphs. If, then, for a particular storm, it is estimated that the volume of runoff will be 2 inches, the ordinates (or discharge values) of this average unit hydrograph are multiplied by 2 to determine the predicted hydrograph of storm runoff. Adding to this the flow occurring just prior to the storm yields the time graph of predicted discharge. FIGURE 5C shows the effect of storm duration on the unit hydrograph. It will be noted that the hydrograph is flatter and that the peak is later for the longer-storm durations.

The unit-hydrograph principle is not generally applicable for basins larger than about 2,000 square miles. Because of variations in the areal distribution of rainfall from storm to storm, forecasts for larger basins must be made by combining the predicted flows for subareas.

Streamflow routing. If the flows from all subareas are simply lagged and added, the resulting hydrograph will be narrower and more peaked than the observed-outflow hydrograph because the storage effect is ignored. The process of translating the flood hydrograph downstream and adjusting it for this storage effect is known as "storage routing" or "flood routing."


PERIOD OF RAINFALL EXCESS
10,000 C.F.S.
STORM RUNOFF FOR 2.0" RAINFALL EXCESS
7500 C.F.S.
STORM RUNOFF FOR 1.5" RAINFALL EXCESS
5000 C.F.S.
STORM RUNOFF FOR 1.0" RAINFALL EXCESS
3750 C.F.S.
2500 C.F.S.
STORM RUNOFF FOR 0.5" RAINFALL EXCESS
1125 C.F.S.
STORM RUNOFF HYDROGRAPH FOR VARIOUS RUNOFF VOLUMES WITH SAME DURATION OF RAINFALL EXCESS
DISCHARGE IN C.F.S.
TIME IN HOURS AFTER START OF RAINFALL EXCESS
A



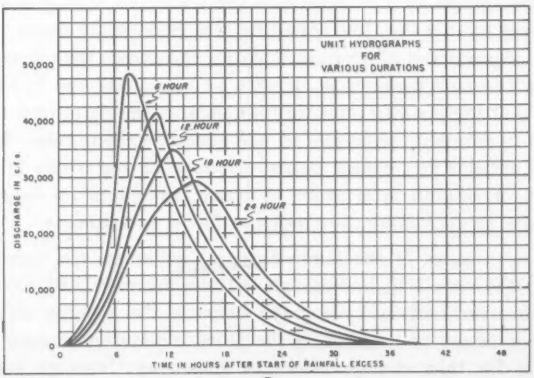


FIGURE 5. The unit-hydrograph principle.

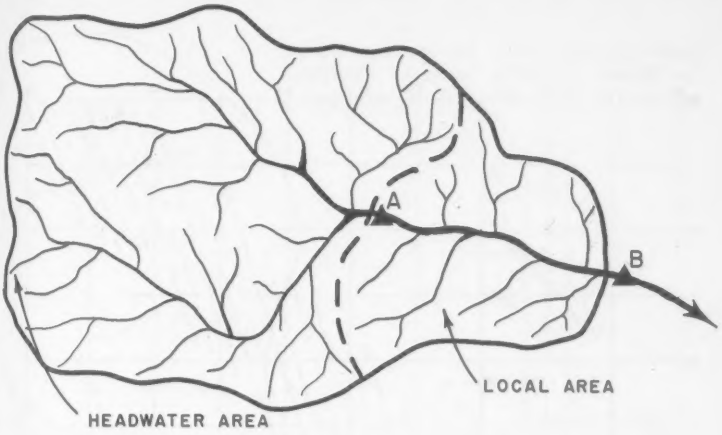


FIGURE 6. A schematic river basin.

To illustrate streamflow routing in its simplest form (FIGURE 6), let us assume that we have a procedure for predicting the flood hydrograph at headwater point *A* and that we wish to develop a procedure for point *B* downstream. Using the upstream rainfall-runoff relation and a "rough" routing procedure, a unit hydrograph would be developed for the local area between the 2 points, and the flow from the local area would be estimated for a number of past floods. These flows would then be subtracted from the observed flows at the lower point. The resulting hydrographs of adjusted outflow are directly attributable to the inflow past the upper station, and the 2 are related through a routing technique.

Many methods of routing have been devised,[2] but most techniques involve solution of the continuity equation and a storage function. The continuity equation in differential form is:

$$\frac{dS}{dt} = I - Q \tag{1}$$

where S is storage, t is time, and I and Q are inflow and outflow discharges, respectively. Since only inflow is known when preparing a forecast, a second equation involving outflow and storage is required for solution. This storage function is usually derived empirically from records of past floods. EQUATIONS 2 and 3 are examples of the functional forms sometimes assumed:

$$S = KQ \tag{2}$$

$$S = K\,[xI + (1-x)\,Q] \tag{3}$$

where K and x represent empirical constants.

FIGURE 5. The unit-hydrograph principle.

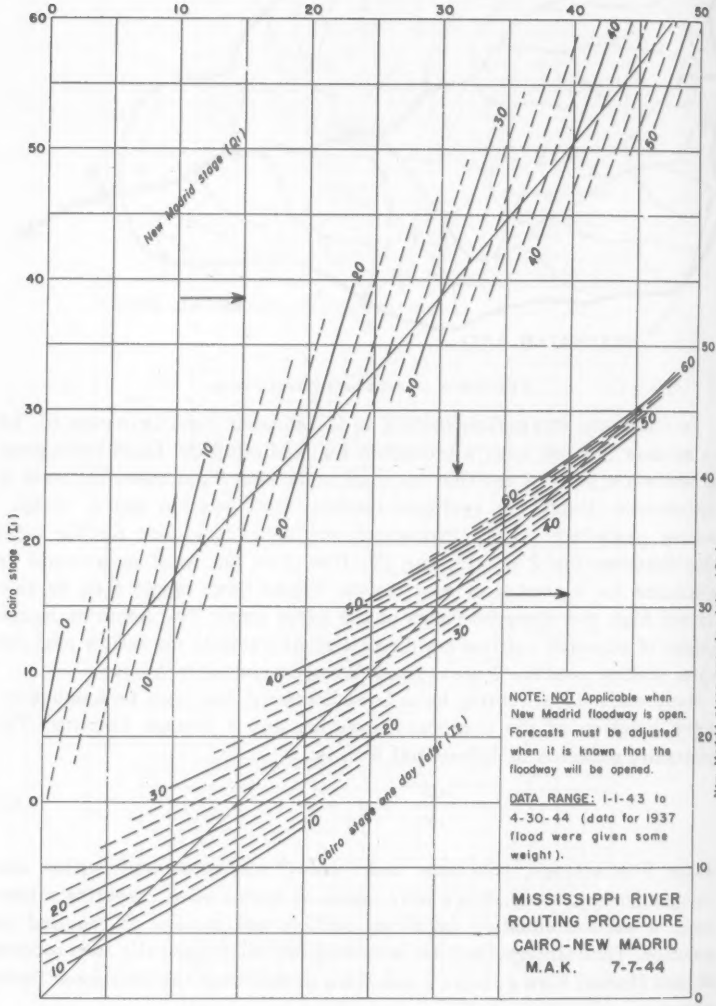

New Madrid stage (Q1)
Cairo stage (I1)
Cairo stage one day later (I2)
New Madrid stage one day later (Q2)
NOTE: NOT Applicable when New Madrid floodway is open. Forecasts must be adjusted when it is known that the floodway will be opened.
DATA RANGE: 1-1-43 to 4-30-44 (data for 1937 flood were given some weight).
MISSISSIPPI RIVER
ROUTING PROCEDURE
CAIRO-NEW MADRID
M.A.K. 7-7-44

FIGURE 7. The coaxial routing relation.

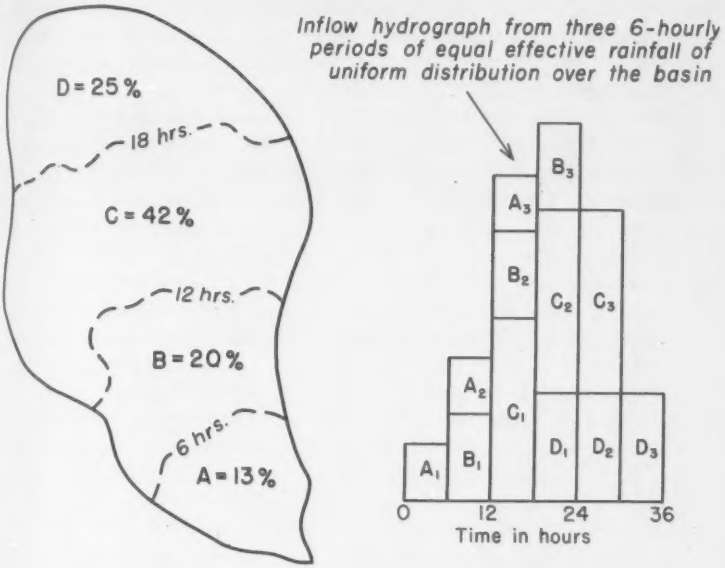


FIGURE 8. Derivation of the inflow graph from effective rainfall.

Electronic analogs[4] are now in use that solve EQUATIONS 1 and 3 simultaneously, and an even more flexible mechanical analog is under development. Most other techniques, however, solve the continuity equation in incremental form. That is:

$$\frac{S_2 - S_1}{t} = \frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2} \tag{4}$$

where the subscripts denote time at beginning and end of the routing period t. Many such routing procedures can be transformed to a coaxial relation of the type shown in FIGURE 7. The relation shown was derived by graphical correlation directly in terms of stage. Entering the upper quadrant with the inflow I_1 and the Q_1 for any particular time, and following vertically downward to the inflow 24 hours later, I_2 yields the computed outflow Q_2 on the appropriate axis. Since the computed outflow for 1 period becomes outflow Q_1 for the following period, the outflow hydrograph can be extrapolated as far in advance as the inflows have been predicted.

By routing the flood hydrograph through successive reaches and adding estimated local flows, forecasts are prepared for an entire basin. Thus it is seen that, in contrast to weather forecasting, downstream river forecasts are based on upstream forecasts that were computed in turn from

other forecasts, and so on. While the compounding of forecasts would seem, offhand, rather insecure, the dampening effect of storage, error compensation, and the curvature of the stage-discharge relation all combine to produce downstream stage forecasts that are generally more accurate than the headwater forecasts from which they were derived.

The chief disadvantage of this system of forecasting lies in the fact that a flexible system of priorities cannot be used. Even though reported precipitation and stage data might indicate a flood to be most serious in downstream reaches, headwater forecasts must be prepared first. Routing of increments of computed runoff from the entire drainage above the point of interest overcomes this deficiency, and this technique is now used in some areas. FIGURE 8 illustrates the first step in converting increments of computed runoff to an estimated flood hydrograph. The basin is divided into zones by lines of constant time of travel above the outflow point. The assumed basin hydrograph is derived by lagging computed runoff, or effective rainfall, over various subareas in proportion to travel time. Thus the blocks A_1, B_1, C_1, and D_1 are in direct proportion to the areas of zones A, B, C, and D, respectively, and therefore constitute the inflow graph for one 6-hour period of runoff evenly distributed over the basin. Similarly, elements with subscripts "2" and "3" are the result of rainfall occurring in the second and third 6-hour periods, respectively. The total inflow graph of storm runoff is thus derived by taking 6-hourly increments of effective rainfall over the various zones, converting these increments to mean flow in cubic-feet per second, and lagging them to the outflow point. The smooth curve through these 6-hourly mean values

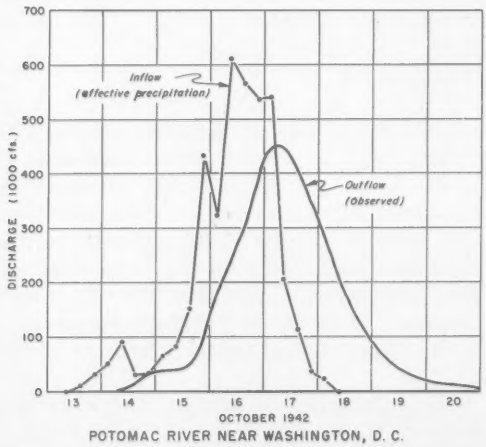


FIGURE 9. A basin inflow and outflow hydrograph.

is considered to represent the inflow to the basin translated to the outflow point. This synthesized hydrograph will differ from the observed hydrograph in the manner shown in FIGURE 9. The difference in this case is analogous to the difference noted when the hydrographs are

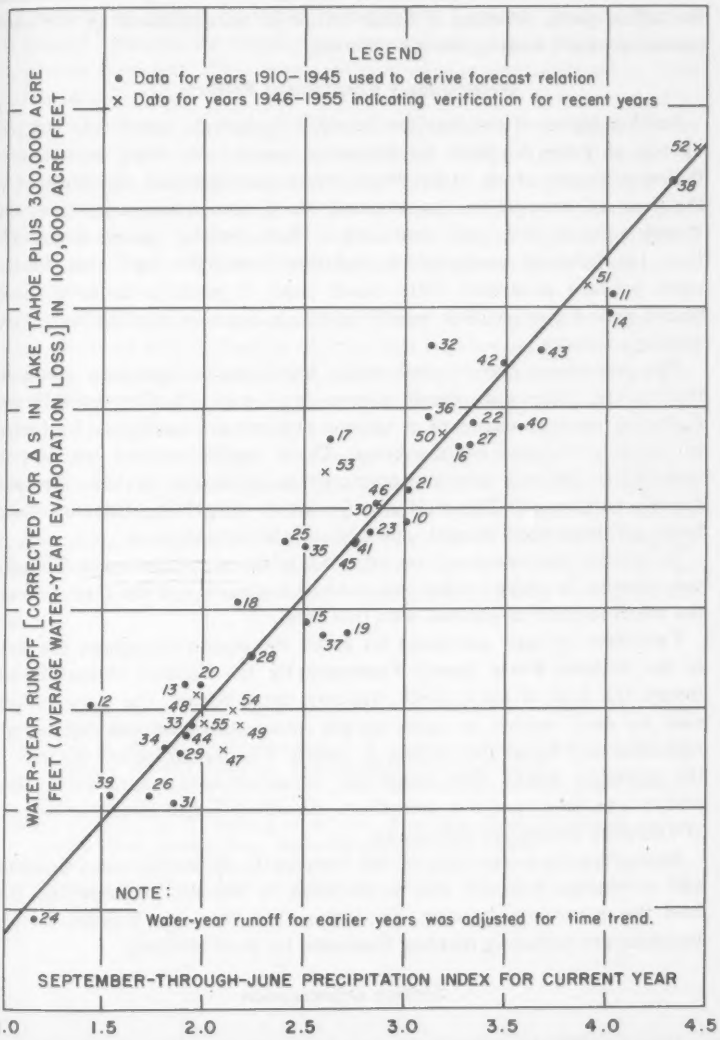


FIGURE 10. A water-supply forecast relation for the Truckee River at Tahoe, Calif.

plotted for 2 points along a channel, and it may be considered the result of storage. On the rising limb, a portion of the inflow is required to fill the channels whereby they can accommodate the increased flows. This stored water is released during the falling limb of the hydrograph with a resultant net decrease in peak flow, that is, the outflow peak is less than the inflow peak. Routing of basin inflow is accomplished in the same manner as reach routing along a channel.

Water-Supply Forecasting Methods

Another phase of the Weather Bureau's hydrologic service is the prediction of water supplies for irrigation, power, and other interests. In the mountainous areas of the West, winter precipitation accumulates in the form of snowpacks. As seasonal temperatures begin to rise, this stored water is released, producing a characteristic spring flood. The time lag between precipitation and runoff and the fact that summer rains produce relatively little runoff make it possible to develop extended-period precipitation runoff relations that are applicable to forecasting purposes.

The procedures now in use[5] relate September-through-June precipitation to the water-year runoff volume (FIGURE 10). The monthly precipitation amounts observed at various stations are multiplied by factors to derive a weighted basin average. These monthly values are, in turn, weighted to derive a seasonal-precipitation index that is then correlated directly with runoff. The station and monthly weights applicable to each basin are determined through multiple correlation analyses.

To prepare early-season forecasts, a statistical estimate of subsequent precipitation is added to that observed up to the date of the forecast, and the runoff relation is entered with this total.

Forecasts are now published for about 350 points throughout the West in the bulletin *Water Supply Forecasts for the Western United States*, issued the first of each month, January through May. The primary forecast for each station is based on the assumption that subsequent precipitation will equal the median of record. Further, to inform the user of the possible effect that variations of subsequent precipitation from median can have upon his operations, runoff estimates based on quartile and extreme values are also given.

Streamflow up to the date of the forecast is known for many stations, and a residual forecast can be obtained by subtracting observed flow from the water-year forecast. Beginning this year, the Weather Bureau bulletins are including residual forecasts for such stations.

Service Organization

Prior to 1946 the entire hydrologic field service of the Weather Bureau was conducted through approximately 80 River District Offices. These

offices were, in reality, first-order Weather Bureau stations, but with added river-service responsibilities. Since weather requires day-by-day attention in contrast to the infrequent nature of floods, and since the officials in charge were better trained in meteorology than in hydrology, relatively little time was devoted to the river program. It appeared that much was to be gained by establishing River Forecast Centers staffed with trained hydrologists whose sole responsibility would be the preparation of river forecasts. This organizational change was initiated in 1946 with the establishment of 2 such centers, and there are now a total of 10 centers, with areas of responsibility covering about two thirds of the United States. Under this organizational plan, (1) the River District Offices supervise the reporting networks, collect the reports, and disseminate the forecasts; and (2) the River Forecast Centers develop forecasting procedures, prepare forecasts on the basis of reports collected by the River District Offices, and transmit the forecasts to the District Offices for dissemination.

With the advent of a radar network there can be little doubt that service rendered by the Weather Bureau will improve materially, particularly with respect to flash-flood warnings on the smaller drainages. Several research and pilot projects are now underway to determine how best to utilize radar in our river program. It is known that our reporting networks are of insufficient density to provide adequate estimates of storm rainfall over small areas. It is also known that time-integrated echoes from the radarscope delineate relative rainfall patterns. We are now attempting to determine the most efficient method of combining the 2 types of observation and the most effective means of using the results to provide reliable flood warnings to communities located in flash-flood areas.

References

1. KOHLER, M. A. & R. K. LINSLEY. 1951. Predicting the runoff from storm rainfall. Weather Bur. Research Paper No. **34**.
2. LINSLEY, R. K., M. A. KOHLER & J. L. H. PAULHUS. 1949. Applied Hydrology. : 412-427, 643-655. McGraw-Hill. New York, N. Y.
3. SHERMAN, L. K. 1932. Streamflow from rainfall by the unit-graph method. Eng. News-Record. **108**: 501-505.
4. LINSLEY, R. K., L. W. FOSKETT & M. A. KOHLER. 1948. Electronic device speeds flood routing. Eng. News-Record. **141**(26): 64-66.
5. KOHLER, M. A. & R. K. LINSLEY. 1949. Recent developments in water-supply forecasting from precipitation. Trans. Am. Geophys. Union. **30**: 427-436.

*SECTION OF ANTHROPOLOGY**

THE NATURE OF LAW**

By Leopold J. Pospisil

Department of Anthropology, Yale University, New Haven, Conn.

Culture, the buffer that mankind has created and placed between men and their environment, has been subdivided by Western thinkers. One of these traditional subdivisions has been called law. Law has been defined in many different ways, and many theories have been advanced as to its nature. Most of the theories are so contradictory, vague, and unpersuasive that many ethnologists omit the category of law when they describe and analyze a given culture.

Another reason why these authors make little use of the legal category lies in the fact that law has usually been defined too narrowly, so that in many "primitive cultures" there is no law present. Thus Radcliffe-Brown says of the Yurok of California: "As the payment of indemnities is arranged by negotiation between the persons concerned and not by appeal to any judicial authority, the law of private delicts in the strict sense is not present."[1]

Should we apply Radcliffe-Brown's statement on law to the culture of the Kapauku of the interior of Netherlands New Guinea, we should obtain an answer similar to his findings among the Yurok. Since there is very seldom an appeal to a rich man to decide a case, and since the payment of indemnities is arranged ultimately by negotiations between the persons concerned, the Kapauku would have a culture void of law. Moreover, if we were to interpret the term "authority" in the customary Western way and look for a person or a body of persons with absolute power whose orders were followed as soon as they were given and whose acts, especially in deciding disputes, were very formal, we should have to agree with some missionaries and some administrators that there is a virtual absence of authority, leadership, and, consequently, of law in this society.

I am of the opinion that the above statements rest on a misunderstanding of the essence of the concept of law that results from placing an undue emphasis upon the formalistic aspects of the legal process and upon descriptive characteristics peculiar to some cultures that alone are believed to define a phenomenon as law. Law is conceived in this article as a functional, rather than as a contentual and descriptive concept. The

*The Division of Mycology held a meeting on May 21, 1956, at which a paper "Parasexual Systems and Their Implications for Phytopathology and Industrial Mycology" was presented by G. Pontecorvo of the Department of Genetics, University of Glasgow, Glasgow, Scotland. No copy of this paper has been received.

**This paper, illustrated with lantern slides and motion pictures, was presented at a meeting of the Section on May 28, 1956.

great majority of writers on law make this assumption, although many of them fail to verbalize it and, consequently, lose sight of it as soon as they try to formulate a category of law. Since the assumption of social control as a function of law constitutes the only common ground on which most of the current definitions of law meet, phenomena that do not exercise social control, such as the dead rules, will not be considered law.

In this article an attempt is made to present a theory of law with cross-cultural applicability, formulated on the basis of a comparative study of 32 cultures and tested in the Kapauku Papuan society.

The form of law. The first problem in the investigation of law concerns the form in which it is manifested. There are a number of possible solutions. Most of the theories of scientists, however, have tended to follow 1 of 3 different paths of thinking.

Some social scientists have studied the abstract rules as they are to be found in legal codifications or in systems of rules that are embedded in people's memories and handed down from generation to generation. According to this trend of thinking, cultures that lack verbalized abstract rules, written or remembered, necessarily have no law.

Regarding the exercising of social control as indispensable for the concept of law, I object to the emphasis on abstract rules as a form of law for several reasons. In the first place, an abstract rule need not exercise the function of social control when it is believed to be outdated, obsolete, or regarded as an ideal that, in actual life, either cannot be realized or can be only approximated. We speak about dead rules that, since they are never applied in deciding legal cases, are therefore now laws, and simply clutter legal codifications.

During my stay among the Kapauku I recorded 176 trouble cases as well as 121 abstract rules. Of the 176 cases, only 87 correspond to a rule. In other words, in 89 cases, almost 51 per cent of the total, the actual results differed from the statements in the rules. Furthermore, 6 rules out of the sample were never applied and can be considered "dead rules." Consequently, a study limited to rules would tell a student of law very little about actual social control among the Kapauku. Not only are many rules not applied, or are even contrary to the customary results of disputes, but the rules themselves are a "mental property" of relatively few of the older individuals.

The difficulties faced by the theoreticians who equated law with abstract rules were clearly seen by Ehrlich[2] and, as a result, he developed the second path for legal thought. He differentiated between rules and what he called "the living law," the actual behavior of the members of the society. I hesitate to conceive law simply as behavior, because the actual behavior of all the members of a social group lacks an ideal aspect and compulsion, and because the identity of the behavior is a

fiction since individuals behave differently. In every society there are persons whose behavior is considered more important than that of other members of the group. Furthermore, to follow Ehrlich's definition of law would lead an investigator of the Kapauku culture to the conclusion that, since the majority of the people would and do steal money if the opportunity presents itself, the "living law" of theft is to steal rather than to prevent the thefts. This finding, in addition to its absurd wording, would fail to bring out the numerous trials and the extensive institutionalized punishments of the thieves.

The decision of an authority offers a third possibility for a conception of law. By such a decision a dispute is solved, or advice is given to a party before any legally relevant behavior takes place, or an approval is granted to a previous solution of a dispute made by the participants before they brought it to the attention of the authority. Among the Kapauku it is not the abstract rule that affects the people, but the actual decision of the headman. People conceive of righteous behavior as what the rich man says and not that which is the content of the rules, although in the majority of the rich man's decisions the people assume that he complies with the rules. A decision serves not only as a solution of a dispute, but it represents a precedent and an ideal even for people who have played no role in the dispute. Since abstractions from the concrete decisions are identical to the "enforced rules," the importance of the latter is neither denied nor diminished by the emphasis here on the idea that decisions form the base of the legal field.

Having established the form of law, we must now lay down objective criteria for the delimitation of its boundaries. The decisions of an authority vary greatly, and they embrace many facts that cannot be called law. In other words, we have to find criteria to differentiate legal decisions from political ones, from advice concerning nonsanctioned customs, and from purely religious phenomena. Many social scientists have been searching for a single criterion of law that would constitute its essence. I do not object to these criteria on the basis of their invalidity. My objection to these views lies in the fact that they are insufficient. It is my contention, based upon the results of comparative research as well as upon the findings among the Kapauku, that not one criterion but rather a whole pattern of them must coexist in time and must cluster around a social fact before it can be called law.

The criterion of authority. A decision, to be legally relevant or, in other words, to effect social control, has to be accepted by the parties to the dispute as a solution of the situation caused by the clash of their interests. Authority is manifested when an individual (or a group) possesses an influence that causes the majority of the members of the group to conform to his decisions. We may ask whether we do not run the risk of making our legal concept nonuniversal by employing such a criterion. Many ethnographers have declared that there is genuine absence of

authority in certain cultures.[3a,3b] Lack of leadership and authority was also claimed in the case of the Kapauku. When we go deeper into our investigation of those cultures, however, we do find particular individuals resolving problems, initiating action in the group, and occupying more or less definite positions of importance. The difficulty lies in the problem of what the respective author actually means by the term authority. Implicit in most of the statements of an absence of authority is a definition that identifies the concept with a person of rather absolute power, whose acts, expecially those involving the passing of decisions, are very formal. We may ask whether absoluteness and formality are the most important characteristics of an authority. I regard, as the essence of the concept, not the above descriptive characteristics peculiar to some cultures only, but the fact that the decisions or advice of the authority are followed by the rest of the members of the group. The concept of an authority, therefore, is considered in this paper not as a descriptive but as a functional one.

My concept of the field of law is as an ellipse surrounded by a zone of transition that separates the field from the rest of the culture. Our criterion of authority defines the lower boundaries of the ellipse and helps us to separate law from the neighboring field of custom. Repetitive behavior that does not form the subject of the authority's decision is simply custom (FIGURE 1).

The criterion of intention of universal application. Since in the culture investigated, both political decisions and legal judgments are made by the same authority, the Kapauku material shows a need for an additional criterion that would be effective in separating the legal and the political fields. To meet this need, I have formulated a criterion called the intention of universal application. To be applicable, this criterion demands that the authority in making a decision intends his decision to be applied to all similar or "identical" situations in the future.

In the decisions of Kapauku authorities, this intention is usually made explicit by either mentioning the pertinent rule or by the use of the obligatory repetitive-tense aspect while referring to the guilt and the punishment. Thus not only does the decision solve a specific case, but it also formulates an ideal—a solution to be utilized in all similar situations.

The criterion of obligatio. This criterion corresponds to that part of the decision of an authority that determines the rights of 1 party and the duties of the other. Both parties must be represented by living persons. Hence all obligations toward the dead and toward the supernatural are excluded from the realm of law unless the interests of the dead or of the supernatural are represented by living people. I differ with Llewellyn and Hoebel[4] on the point that a religious taboo "with no officials to enforce it" is not law, but a strictly religious phenomenon. If we were to include

such taboos in the legal field, this field would cease to exist because any kind of custom could creep in and break down its boundaries. Thus the criterion of obligatio separates religious customs from religious law.

It will be noticed that the obligatio is different from the popular concept of obligation which only includes duty. The concept, as presented

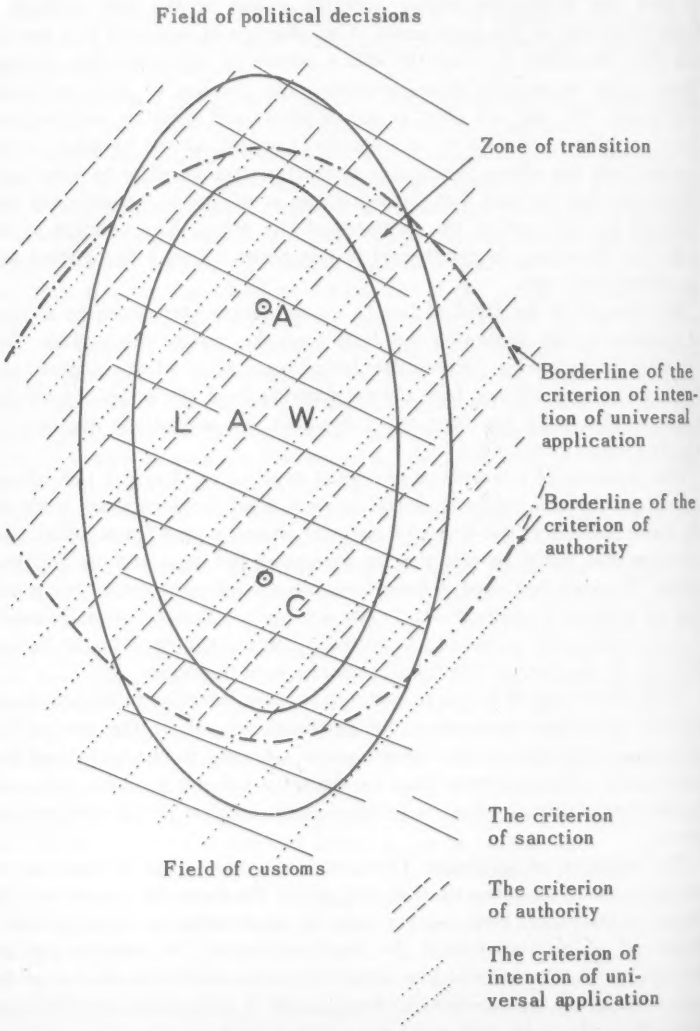

Field of political decisions
Zone of transition
A
L A W
C
Borderline of the criterion of intention of universal application
Borderline of the criterion of authority
Field of customs
The criterion of sanction
The criterion of authority
The criterion of intention of universal application

FIGURE 1. The criteria of law.

here, is a statement about a social relation, and it has 2 directions: one going from the privileged party to the obligated party, which is called the right; and the other going from the obligated party toward the privileged one, which is called the duty. Only when these 2 directions coexist in a decision may we call it a law.

The criterion of sanction. This criterion has played a paramount role in different legal theories. Sometimes law has been almost equated with it. I do not attempt to underestimate its importance. Nevertheless, I should question the exclusive use of this criterion and its superordination above the rest of the legal factors, the coexistence of which we have used in defining a phenomenon as law. We have to realize that although many political decisions are provided with sanctions, they are not laws, for there is a lack of the repetitive aspect or, in other words, an absence of the criterion of intention of universal application.

As to the legal sanction itself, it has been usually conceived of as having a physical nature.[5] If we were to accept this definition of sanction, many of the Kapauku cases would not be legal, and law would not be a universal phenomenon, for cultures exist where physical sanction is practically lacking. We may ask if the form of sanction is so important as to make the existence of law dependent upon it. Is not the effect (social control, conformity) of a sanction more important than its form? In this case, as in defining the concept of authority, I prefer a functional approach. I suggest that social control is the important qualification of a legal sanction. Some psychological sanctions, although of nonphysical nature, exercise as strong a control as do physical sanctions. Ostracism, ridicule, avoidance, or a denial of favors—sanctions that are sometimes very subtle and informal—nevertheless may become more drastic than the corporal punishment to which we tend to attach overimportance even in our own culture. The Kapauku consider being shamed by a public reprimand much worse than anything except capital punishment. Thus we can define a legal sanction as either the negative behavior of withdrawing some rewards or favors that otherwise (if the law had not been violated) would have been granted, or the positive behavior of inflicting some painful experience, be it physical or psychological.

Legal levels. With the discussion of sanctions, we have completed our analysis of the pattern of criteria that define a phenomenon as law. Now we have to decide were to look in a society for "legal decisions."

In addition to the society as a whole, with its authorities and their rules that traditionally have been called law, there are subgroups such as families, clans, and communities that are usually omitted in legal analysis. My own comparative research brought out the fact that the members of any functioning group and, therefore, also of the society's subgroups, are organized into a hierarchical structure. In each case an authority is present and he has followers. All these authorities make

decisions having those legal criteria that have been discussed. We may claim, then, that law as identified by our 4 criteria is present not only on the society level but also in its subgroups, so long as they are functioning units. The particular laws of a functioning group form a legal system.

Many ethnographers assume that a given society has a single legal system. They either neglect legal phenomena on the subgroup levels, or they project these phenomena into the top society level and make them consistent with it. Instead of accepting this smoothed-out picture of a single legal system in a society, I suggest recognition of the fact that there are as many such systems as there are functioning groups. The legal systems of families, clans, and communities, for example, form a hierarchy of what we may call legal levels, according to the inclusiveness of the respective groups. A legal level may be defined as the sum total of all the legal systems of groups of approximately the same degree of inclusiveness. Because there is usually an inconsistency in the contents of law between the different legal levels, even to the point of contradictions, an individual is subjected not to only a single legal system but to the different legal systems of all the groups of which he is a member.

The law of the society as a whole may not only be ineffective in bringing about a conformation in the legal content of the subgroups, but it also may become lost in the power of 1 level of the groups over another. In Western culture we are accustomed to the belief that the law of the state is the primary standard to which the individual looks for protection and security, and to which he tries to adjust his behavior. Only after the individual has made this adjustment can there be control by a family or a clique. In many other cultures the situation is different—the center of power is located on the lower levels while the society level is so weak that it is frequently difficult to speak of an authority and a law. Since Kapauku society is not a functioning unit and since there are no authorities on the society's level, an anthropologist writing on the "law of the Kapauku society" would, in the strictest sense, be writing about nonexistent phenomena. It is primarily at the levels of the political district and its subgroups that we must look for law in that society.

The conception of a society as a multilevel unit with a center of power brings together certain phenomena and processes that otherwise would be put into different categories and would be treated differently. It helps us to understand why a man in one society is primarily a member of his kin-group or village and only secondarily of the state, while in another society the state may play the most important role. Consequently it is inconsistent to make a qualitative distinction between the law of the state and the "criminal gang's ethics."[6] Both of these phenomena belong to the same category, and both should be classified as laws. It is

unfortunate that in the West the concept of law has acquired a moralistic connotation.

Legal dynamics. In order to determine in what way law is related to political decisions on the one hand and to customs on the other, we have first to investigate the traditional dichotomy between 2 types of law, the difference between customary law and the "legislator's (authoritarian) law."

By customary law I mean a law that is internalized by a social group. We call a law internalized when the majority of the members of the group consider it to be binding, as when it stands for the "only proper behavior in a given situation." Conformity to such a law is not primarily effected by external pressure. It is produced by a different, internal mechanism that we may call conscience in some cultures and fear of shame in others. This is the type of law that the ethnographer has usually described and has claimed to be the property of the group.

The authoritarian law, on the other hand, is not internalized by a majority of the members of the group. A strong minority that supports the legal authority may have elevated such a law to an ideal and may have simply forced the rest of the people to accept it. The opposing members of the group comply with such a law mainly because of external pressure exercised upon them by the authority and the strong minority who may already have internalized it. The majority of the population feels no guilt in the event of violation of such a law. There may be only fear of detection. According to my findings, authoritarian law is a universal phenomenon present to varying degrees in every society no matter how "primitive" or "civilized."

The difference between the 2 types of law is not a qualitative one. Rather, it is the degree of internalization that causes a particular law to be called either customary or authoritarian. A given law is consequently a dynamic phenomenon. An increase of its supporters would change it from authoritarian to customary. A decrease would produce an opposite effect (FIGURE 2).

A new law may originate in 2 ways. First, it can enter the legal field from the realm of custom (FIGURE 2, *g*). This happens when the authority recognizes a custom as the basis for legal decisions.

The second possible origin of law may be a direct creation by the decision of an authority, or the transformation of a political decision into a law by the authority's proclamation, for instance, that the decision is intended to be applied to all similar cases in the future. Among the Kapauku, a village headman in the South Kamu Valley, by his decisions, changed the former sib exogamy, whose violation was punishable by execution, to a preferential sib endogamy. Thus an important change in the law of incest and consequent profound changes in the social structure were initiated in the South Kamu by a single man—a village legal authority.

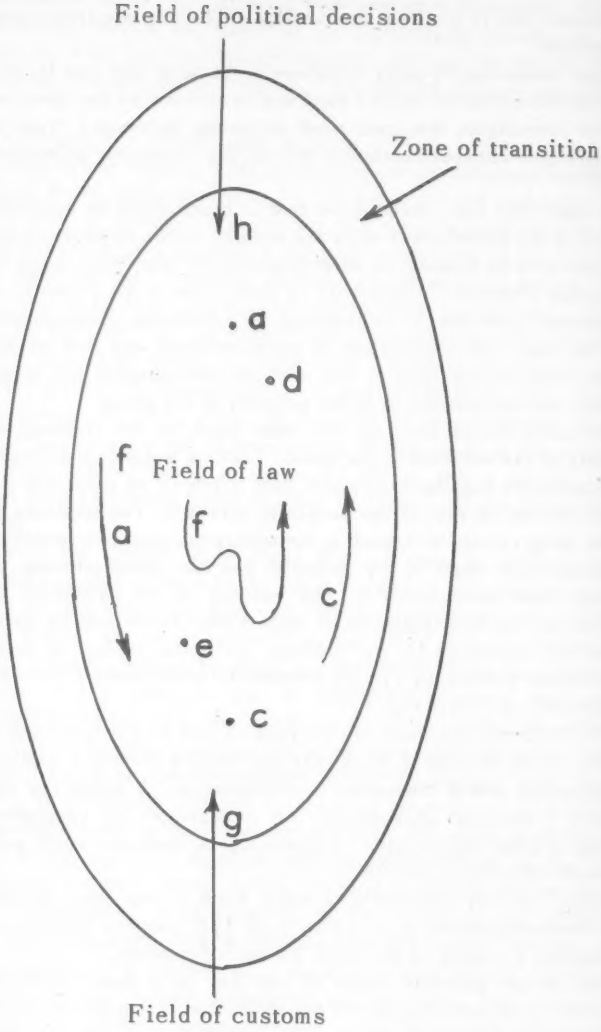


FIGURE 2. Legal dynamics: *a*, internalization of a law; *c*, extinction of a law; *f*, original internalization of a law changes, after some fluctuation, into extinction; *d* and *e*, static laws; *g*, a custom becomes law; *h*, a political decision becomes law.

The relativity of law. The combination of the principles of legal levels with the ideas of authoritarian and customary law reveals the relative nature of the 2 concepts. The same law that is customary on the level of a more inclusive group at the same time may be authoritarian when considered as the law of subgroups in which it has not yet been internalized. The Kapauku village headman of the South Kamu, for example, introduced a new law of incest regulation. While the new law was customary on the village level because the majority of the village people accepted it as proper, it was authoritarian in those families in which the majority of the family members had not yet internalized it, although the law was enforced by the family heads.

The principle of legal levels brings out another important matter—the relativity of law and custom. A phenomenon on the level of the Kapauku political district may be called custom as, for example, the services of an economic nature that the household members offer to the head of the household. This custom, however, which is never enforced on village levels, is certainly to be regarded as law if one focuses his attention upon the household level.

Law and custom are concepts relative to the level of investigation. If someone asks whether a specific social relation is law or custom in a given society, we have to ask in turn, "Do you mean law of the society, of the community, of the clan, or of the family?" The decision in favor of law or custom will be relative to the answer given to this question.

References

1. RADCLIFFE-BROWN, A. R. 1952. Structure and Function in Primitive Society. : 216. The Free Press. Glencoe, Ill.
2. EHRLICH, E. 1913. Grundlegung der Sociologie des Rechts. : 65, 323-324. Duncker & Humblot. München & Leipzig, Germany.
3a. YANG, M. C. 1945. A Chinese Village. : 134. Columbia Univ. Press. New York, N. Y.
3b. GUSINDE, M. 1937. Die Feuerland Indianer—Die Yamana. Publ. Anthropos. Modling bei Wien. : 628.
4. LLEWELLYN, K. N. & E. A. HOEBEL. 1941. The Cheyanne Way. : 286. Univ. Okla. Press. Norman, Okla.
5. HOEBEL, E. A. 1954. The Law of Primitive Man. : 28. Harvard Univ. Press. Cambridge, Mass.
6. HOEBEL, E. A. 1954. The Law of Primitive Man. : 27. Harvard Univ. Press. Cambridge, Mass.

CONFERENCES HELD

TECHNIQUES FOR THE STUDY OF BEHAVIORAL EFFECTS OF DRUGS

Friday, May 4, 1956

Conference Co-Chairmen
Peter B. Dews, Harvard Medical School, Boston, Mass.
B. F. Skinner, Harvard Medical School, Cambridge, Mass.

Session Chairman: B. F. Skinner
Harvard Medical School, Cambridge, Mass.

9:00 A.M. –
Greetings from the Academy – Hilary Koprowski, Chairman, Section of Biology, New York Academy of Sciences, New York City; Lederle Laboratories Division, American Cyanamid Company, Pearl River, N. Y.

"Effects of Drugs on Behavior Patterns of Cats" – E. J. de Beer and S. Norton, Wellcome Research Laboratories, Tuckahoe, N. Y.

"Effects of Drugs in Classical Conditioning" – H. Hunt, University of Chicago, Chicago, Ill.

"Modification by Drugs of Performance on Simple Schedules of Positive Reinforcement" – Peter B. Dews, Harvard Medical School, Boston, Mass.

"Drug-behavior Interaction" – M. Sidman, Walter Reed Army Medical Center, Washington, D. C.

"The Effects of Drugs on Characteristics of Behavior Maintained by Complex Schedules of Intermittent Positive Reinforcement" – W. H. Morse and R. J. Herrnstein, Harvard University, Cambridge, Mass.

Session Chairman: Peter B. Dews
Harvard Medical School, Boston, Mass.

2:15 P.M. –
"Effects of Drugs on Motivation: Value of Using a Variety of Measures" – N. Miller, Yale University, New Haven, Conn.

"Technique for Studying Effects of Drugs on Discrimination in the Pigeon" – D. Blough, National Institutes of Health, Bethesda, Md.

"The Description and Analysis of Mood" – V. Nowlis, University of Rochester, Rochester, N. Y.

Concluding Remarks – B. F. Skinner, Harvard University, Cambridge, Mass.

ANESTHESIOLOGY

Friday, May 18 and
Saturday, May 19, 1956

Conference Co-Chairmen
C. R. Stephen, Duke University School of Medicine
Durham, N. C.
E. J. de Beer, Wellcome Research Laboratories
Tuckahoe, N. Y.

FRIDAY AFTERNOON, MAY 18, 1956

GERIATRIC ANESTHESIA

Session Chairman: Vincent J. Collins
St. Vincent's Hospital, New York, N. Y.

2:00 P.M. –
Greetings from the Academy – Hilary Koprowski, Chairman, Section of Biology, New York Academy of Sciences, New York City; Lederle Laboratories Division, American Cyanamid Company, Pearl River, N. Y.

"Hematologic and Nutritional Factors" – Charles M. Barbour, Hartford Hospital, Hartford, Conn.

"Evaluation of Cardiovascular Complications" – Elliott V. Newman, Vanderbilt University School of Medicine, Nashville, Tenn.

"Problems Related to Pulmonary Dysfunction" – John B. Hickam, Duke University School of Medicine, Durham, N. C.

"Choice of Anesthesia in the Geriatric Patient" – C. R. Stephen, Duke University School of Medicine, Durham, N. C.

CONTROLLED RESPIRATION IN ANESTHESIA

Session Chairman: Meyer Saklad
Rhode Island Hospital, Providence, R. I.

8:00 P.M. –
"Factors of Significance in the Respiratory System" – William A. Spencer, Baylor University College of Medicine, Houston, Texas.

"Factors of Significance in the Cardiovascular System" – James V. Maloney, University of California Medical Center at Los Angeles, Calif.

"The Methodology of Controlled Respiration" – David M. Little, Jr., Hartford Hospital, Hartford, Conn.

"Controlled Respiration and the Evolution of Anesthetic Practice" Emanuel Papper, Columbia University College of Physicians and Surgeons, New York, N. Y.

SATURDAY, MAY 19, 1956

FLUID AND ELECTROLYTE BALANCE IN SURGERY

Session Chairman: Virginia Apgar
Columbia University College of Physicians and Surgeons,
New York, N. Y.

9:00 A.M. –

"Body Mechanisms for Fluid and Electrolyte Control" – Henry T. Randall, Cornell University Medical School, New York, N. Y.

"Respiratory Alkalosis and Metabolic Acidosis" – Kathleen E. Roberts, Cornell University Medical College, New York, N. Y.

"Special Pediatric Problems" – Jerome S. Harris, Duke University School of Medicine, Durham, N. C.

"Contributions of Radioactive Isotopes to the Study of Electrolyte Balance in Surgery" – Betty M. Cooper, Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tenn.

HYPOTENSION IN THE OPERATING ROOM

Session Chairman: Ralph M. Tovell
Hartford Hospital, Hartford, Conn.

2:00 P.M. –

"Relationship of Anesthetic Drugs to Hypotension" – Robert T. Patrick, Mayo Clinic, Rochester, Minn.

"Adrenal Insufficiency during Surgical Anesthesia" – Chas. L. Burstein, Hospital for Special Surgery, New York University Post-Graduate Medical School, New York, N. Y.

"Hypotension and the Autonomic Nervous System" – Domingo M. Aviado, Jr., University of Pennsylvania School of Medicine, Philadelphia, Pa.

"Protective Mechanisms in Experimental Shock" – B. W. Zweifach and S. G. Hershey, New York University – Bellevue Medical Center, New York, N. Y.

VIRUSES IN SEARCH OF DISEASE

Thursday, May 24 and
Friday, May 25, 1956

Conference Chairman: Robert J. Huebner
Chief, Laboratory of Infectious Diseases
National Institute of Allergy and Infectious Diseases
National Institutes of Health, Bethesda, Md.

THURSDAY, MAY 24, 1956

COXSACKIE VIRUSES

Session Chairman: Gilbert Dalldorf
Division of Laboratories and Research, New York
State Department of Health, Albany, N. Y.

9:00 A.M.–
Greetings from the Academy – Hilary Koprowski, Chairman, Section of Biology, New York Academy of Sciences, New York City; Lederle Laboratories Division, American Cyanamid Company, Pearl River, N. Y.

"Brief Review of Coxsackie Viruses in 1956" – Gilbert Dalldorf, Division of Laboratories and Research, New York State Department of Health, Albany, N. Y.

"Aseptic Meningitis: Evidence for the Etiologic Role of Coxsackie Group B and Orphan Viruses" – A. J. Rhodes, The Hospital for Sick Children, Toronto, Canada.

"Isolation of Coxsackie Viruses from Cases of Aseptic Meningitis" – Karl Habel and Alexis Shelokov, National Institutes of Health, Bethesda, Md.

"Clinical Importance of Group A Coxsackie Viruses" – Robert Parrott, National Institutes of Health, Bethesda, Md.

Discussion Panel: Gilbert Dalldorf, Robert Parrott, A. J. Rhodes, John F. Enders, Karl Habel, Klaus Hummeler, Alex J. Steigman

Open Discussion

NEW RESPIRATORY AND OCULAR VIRUSES

Session Chairman: John H. Dingle
Western Reserve University, Cleveland, Ohio

2:00 P.M.–
"Definition and Outline of Contemporary Information of the APC Group

of Viruses" – Wallace P. Rowe, National Institutes of Health, Bethesda, Md.

"Epidemiology of RI Virus Infections in Military Recruits" – Maurice Hilleman, Walter Reed Army Medical Center, Washington, D.C.

"Frequency of Infection with New Respiratory Viruses in a Family Study Group Population" – William S. Jordan, Jr., Western Reserve University, Cleveland, Ohio.

"Clinical Entities Associated with Sporadic Infection with APC Viruses in Adults" – Ernest Jawetz, University of California Medical Center, School of Medicine, San Francisco, Calif.

"Association of a New Type of Cytopathogenic Virus with Infantile Croup" – R. M. Chanock, Children's Hospital Research Foundation, Cincinnati, Ohio.

Discussion Panel: Wallace P. Rowe, Maurice Hilleman, William S. Jordan, Jr., Ernest Jawetz, R. M. Chanock, R. Walter Schlesinger, R. Shih-Man Chang, J. Thomas Grayston

Open Discussion

ECHO VIRUSES

Session Chairman: John F. Enders
Children's Hospital, Boston, Mass.

8:00 P.M. –

"Problems Raised by Certain Echo Viruses in the Attempted Laboratory Detection of Poliomyelitis Virus Infection" – W. McD. Hammon, University of Pittsburgh, Pittsburgh, Pa.

"Clinical Associations of Enteric Viruses" – Sidney Kibrick, The Children's Hospital, Boston, Mass.

"Cytopathogenic Enteric Viruses Associated with Undifferentiated Diarrheal Syndromes in Early Childhood" – M. Ramos-Alvarez, Children's Hospital Research Foundation, Cincinnati, Ohio.

"Aseptic Meningitis Caused by Orphan Viruses and Other Agents" – H. Meyer, Jr., N. Rogers, M. Miesse, and I Crawford, Walter Reed Army Medical Center, Washington, D. C.

"A New Viral Agent Associated with Fifth Disease" – P. Brachman, G. Rake, G. Werner, A. Ketler, and J. Scully, University of Pennsylvania School of Medicine, Philadelphia, Pa.

Discussion Panel: W. McD. Hammon, P. Brachman, Sidney Kibrick, S. A. Sabin, M. Ramos-Alvarez, Franklin A. Neva, H. Meyer, Jr., Cyril S. Stulberg

Open Discussion

FRIDAY, MAY 25, 1956

VIRAL IDENTIFICATION AND CLASSIFICATION

Session Chairman: R. Walter Schlesinger
St. Louis University Medical School, St. Louis, Mo.

9:00 A.M. –
"Problems Associated with Viral Identification and Classification in 1956" – Joseph Melnick, Yale University School of Medicine, New Haven, Conn.

"Biologic and Physical Properties of Respiratory Viruses" – Harold S. Ginsberg, Western Reserve University, School of Medicine, Cleveland, Ohio.

"Mechanisms of Persistent and Masked Infections in Tissue Culture" – W. Wilbur Ackermann, University of Michigan School of Public Health, Ann Arbor, Mich.

"Problems in Characterizing and Identifying an Apparently New Virus Found in Association with Mild Respiratory Disease in Recruits" – William J. Mogabgab and W. Pelon, Tulane University School of Medicine, New Orleans, La.

"New Viral Agents Recovered from Tissue Cultures of Monkey Kidney Cells: Problems of Isolation and Identification" – Robert N. Hull and J. Minner, Eli Lilly & Company, Indianapolis, Ind.

Discussion Panel: Joseph Melnick, Robert N. Hull, Harold S. Ginsberg, Joseph E. Smadel, W. Wilbur Ackermann, J. S. Youngner, William J. Mogabgab, Thomas Weller

Open Discussion

CRITERIA FOR ETIOLOGIC ASSOCIATION OF PREVALENT VIRUSES WITH PREVALENT DISEASE

Session Chairman: Herbert Morgan
University of Rochester Medical School, Rochester, N. Y.

2:00 P.M. –
"Outline of Problem" – Robert J. Huebner, National Institutes of Health, Bethesda, Md.

Discussion Panel: Robert J. Huebner Thomas Francis, Jr.
Frank L. Horsfall, Jr. John H. Dingle
Thomas Ward

Open Discussion

ORGANIZING COMMITTEE

Robert J. Huebner, *Chairman*

John F. Enders	Herbert Morgan
R. Walter Schlesinger	Gilbert Dalldorf
John H. Dingle	Hilary Koprowski

NEW MEMBERS

Elected May 15, 1956

LIFE MEMBERSHIP

Kukral, Jan Josef, M.D., Anesthesiology. Anesthesiologist, Evangelical Hospital, Chicago, Ill.

SUSTAINING MEMBERSHIP

Gould, Jack U., M.E., Engineering. Director, Research & Engineering, Ferdinand Gutmann & Co., Brooklyn, N. Y.

Levinskas, Leo, M.D., Biology. General Practioner, Hamilton General Hospital, Hamilton, Ont., Canada.

Scheer, Irvin Joseph, M.D., Biology. Private Practice, Chicago, Ill.

ACTIVE MEMBERSHIP

Adam, Briancon Luis., M.D., Bacteriology. Professor de Bacteriología y Inmunología, University of San Francisco Xavier de Chuquisaca, Sucre, Bolivia.

Barron, Almen L., Ph.D., Virology. Instructor, University of Buffalo, Buffalo, N. Y.

Bashour, Fouad Anis, M.D., Internal Medicine. Instructor, Medicine, University of Minnesota Hospital, Minneapolis, Minn.

Bonaventura, F. A., M.D., Endocrinology. Private Practice, San Diego, Calif.

Bonfiglio, Michael, M.D., Orthopedic Surgery. Assistant Professor, University of Iowa, Iowa City, Iowa.

Boren, John, Ph.D., Experimental Psychology. Research Associate, Merck, Sharp & Dohme, Inc., West Point, Pa.

Brackett, Nathaniel Parker, Jr., M.D., Medicine. Private Practice, Waltham, Mass.

Buchenholz, Bruce, M.D., Psychiatry. Assistant Professor, Psychiatry, Columbia University, New York, N. Y.

Callaway, Enoch, III, M.D., Psychiatry. Assistant Professor, Psychiatry, University of Maryland, College Park, Md.

Chase, Richard Allen, B.A., Medical Psychology. Student, Columbia University College of Physicians and Surgeons, New York, N. Y.

Coblens, Harry C., M.D., Medicine. Private Practice, Chicago, Ill.

Cole, Paul Frank, B.S., Medicine. Clinical Research Coordinator, Chas. Pfizer & Co., Inc., Brooklyn, N. Y.

Comens, Phillip, M.D., Collagen Diseases. Research Fellow, Washington University, St. Louis, Mo.

Deamer, William C., M.D., Pediatrics. Professor, Pediatrics, University of California, San Francisco, Calif.

De Liz Ferreira, Antonio J., M.D., Medicine. Worcester State Hospital, Worcester, Mass.

De Salva, Salvatore Joseph, M.S., Pharmacology. Pharmacologist, Armour Laboratory, Chicago, Ill.

Deutsch, Erwin, M.D., Biology. Docent, University of Vienna, Vienna, Austria.

Dille, J. M., M.D., Biology. Professor, Pharmacology, University of Washington, Seattle, Wash.

Edmeades, Donald T., M.D., Cardiology. Associate Professor, Medicine, University of Southern California, Los Angeles, Calif.

Ehrlich, David A., M.A., Public Opinion. Professional Relations Director, L. W. Frohlich & Co., Inc., New York, N. Y.

Fand, Sally Bogolub, M.D., Endocrinology. Medical Officer, National Cancer Institute, Bethesda, Md.

Ferguson, Albert B., M.D., Medicine. Children's Hospital, Pittsburgh, Pa.

Finn, Michael H. P., Ph.D., Clinical Psychology. Chief Psychologist, Springfield State Hospital, Sykesville, Md.

Flanagan, Charles Larkin, M.D., Internal Medicine. Research Associate, University of Chicago, Chicago, Ill.

Frank, B. L., D.P.H. Medicine. Lecturer, Medicine, McGill University, Montreal, P.Q., Canada.

Gammell, Deuman Thompson, M.D., Biology. Private Practice, Hugoton, Kans.
Gerow, James Hadley, M.D., Surgery. Private Practice, Oregon City, Oreg.
Glass, Dorothea Daniels, M.D., Internal Medicine. Fellow, Preventive Medicine, Woman's Medical College of Pennsylvania, Melrose Park, Pa.
Gottlieb, Leonard S., M.D., Pathology. Laboratory Officer, U. S. Naval Hospital, Chelsea, Mass.
Gremmel, Warren Walter, M.D., Medicine. Private Practice, Atlanta, Ga.
Gross, Stanley, M.D., Pathology. Director, Laboratories, North Shore Hospital, Manhasset, N. Y.
Guild, Warren Redwood, M.D., Cardiorenal Research. Research Fellow, Harvard Medical School, Boston, Mass.
Gunnar, Rolf McMillan, M.D., Internal Medicine. Clinical Instructor, Medicine, University of Illinois, Chicago, Ill.
Gusberg, Saul Bernard, M.D., Medicine. Associate Attending Obstetrician, Presbyterian Hospital, New York, N. Y.
Hall, Mary A., M.D., Medicine. Private Practice, Milwaukee, Wis.
Hamm, Goldie Suttle, M.D., Gynecology. Private Practice, Houston, Texas.
Hardy, Janet B., M.D.C.M., Pediatrics. Director, Bureau of Child Hygiene, Baltimore City Health Department, Baltimore, Md.
Harrison, Preston Ershell, M.D., Psychiatry. Clinical Director, Big Spring State Hospital, Big Spring, Texas.
Hartroft, Phyllis Merritt, Ph.D., Experimental Histology. Research Assistant, Washington University, St. Louis, Mo.
Harvey, Daryl P., M.D., Medicine. Private Practice, Glasgow, Ky.
Heald, Felix, M.D., Adolescence. Instructor, Pediatrics, Harvard Medical School, Boston, Mass.
Hebertson, Wayne M., M.D., Neurology. Chief Resident, Neurology, Massachusetts General Hospital, Boston, Mass.
Helwig, John, Jr., M.D., Internal Medicine. Assistant Surgical Resident, University of Pennsylvania Hospital, Philadelphia, Pa.
Herman, Doris L., M.D., Pathology. Resident, Pathology, Los Angeles County General Hospital, Los Angeles, Calif.
Hillabrand, John F., M.D., Cytology. Maumee Valley Hospital, Toledo, Ohio.
Hirsch, Theodore, M.D., Medicine. Private Practice. Hialeah, Fla.
Hitch, Joseph M., M.D., Medicine. Clinical Associate Professor, Medicine, University of North Carolina, Chapel Hill, N. C.
Holland, Albert H., Jr., M.D., Medicine. Medical Director, Food & Drug Administration, Washington, D. C.
Hoon, James Richard, M.D., Surgery. Surgeon, The Sheboygan Clinic, Sheboygan, Wis.
Huber, Robert Bernard, M.D., Medicine. Chief Resident, Pediatrics, Children's Memorial Hospital, Chicago, Ill.
Hughes, John J., M.D., Medicine. Trainee, Cardiology, University of California, San Francisco, Calif.
Huguley, Charles M., Jr., M.D., Internal Medicine. Assistant Professor, Medicine, Emory University, Emory University, Ga.
Jordan, Russell Thomas, Ph.D., Virology. Chairman, Department, Microbiology, University of California, Los Angeles, Calif.
Justman, Daniel, M.D., Psychiatry. Resident, Psychiatry, New York State Psychiatric Institute, New York, N. Y.
Kallio, R. E., Ph.D., Bacterial Metabolism. Associate Professor, University of Iowa, Iowa City, Iowa.
Kaplan, Ervin, M.D., Internal Medicine. Assistant to Chief, Medicine, Veterans Administration Hospital, Hines, Ill.,
Karowe, Harris E., M.D., Biology. Private Practice, Waltham, Mass.
Kelemen, George, M.D., Olo-Rhmology. Associate Clinical Professor, Harvard Medical College, Boston, Mass.
Kelsey, Frances Oldham, M.D., Pharmacology. Associate Professor, Pharmacology, University of South Dakota, Vermillion, S. Dak.
Kessler, Morris M., M.D., Psychoanalysis. Clinical Instructor, Psychiatry, Western Reserve University, Cleveland, Ohio.
Kilbourne, Edwin D., M.D., Microbiology. Associate Professor, Preventive Medicine, Cornell University Medical College, New York, N. Y.

King, Harry, M.D., Pediatrics. Pediatrician, Long Island Jewish Hospital, Long Island, N. Y.

Kirk, Daniel Lee, M.D., Neuropsychiatry. Clinical Director, Elwyn Training School, Elwyn, Pa.

Kistner, Robert W., M.D., Biology. Private Practice, Brookline, Mass.

Knapp, Joseph L., M.D., Psychiatry. Associate Psychiatrist, Beverly Hills Sanitarium, Dallas, Texas.

Koch, Richard E., D.S., Geology. Retired, Lugano, Switzerland.

Konicoff, Donald Stephen, B.S., Biology. Medical Student, New York Medical College, New York, N. Y.

Kopp, Joseph B., M.D., Internal Medicine. Assistant, Hematologist, Buffalo General Hospital, Buffalo, N. Y.

Kraus, Shirley Dushkind, Ph.D., Pharmacology. Howard University, Washington, D. C.

Kreshover, Seymour J., M.D., Oral Pathology. Professor, Oral Pathology, Medical College of Virginia, Richmond, Va.

Krieger, Harvey, M.D., Metabolism. Assistant Professor, Surgery, Western Reserve University, Cleveland, Ohio.

Kroll, Harvey Vincent, M.D., Internal Medicine. Department of Internal Medicine, Jennings Memorial Hospital, Detroit, Mich.

Kuhn, Richard, Ph.D., Organic Chemistry. Director, Max-Planck Institute Heidelberg, Germany.

Lake, Henry, M.D., Medicine. Medical Staff, Williamsburgh General Hospital, Brooklyn, N. Y.

Lambright, M. H., Jr., M.D., Surgery. Private Practice, Cleveland, Ohio.

La Mantia, Luigi, M.D., Immunology. Research Fellow, Chicago Medical School, Chicago, Ill.

Laron, Zvi, M.D., Pediatrics. Children's Hospital, Pittsburgh, Pa.

Larowche, Gerard, M.D., Biology. Medical Resident, Mountainside Hospital, Montclair, N. J.

Lawrence, Carl A., Ph.D., Biology. Director, Bureau of Laboratories, Los Angeles County Health Department, Los Angeles, Calif.

Lawrence, James V., Ph.D., Bacteriology. Assistant Professor, Bacteriology, Ohio University, Athens, Ohio.

Leach, Robert Bingham, M.D., Internal Medicine. Assistant Professor, Medicine, Wayne University, Detroit, Mich.

Leslie, Harry B., M.D., Pediatrics. Private Practice, Cleveland, Ohio.

Lesse, Henry, M.D., Psychiatric Research. Career Investigator, National Institute of Mental Health, New Orleans, La.

Levine, Herman R., M.D., Cardiology. Private Practice, Brooklyn, N. Y.

Levine, Morton, B.S., Biochemistry. Research Assistant, Pittsburgh, Pa.

Levy, David Alfred, M.D., Internal Medicine. Assistant Resident, Medicine, University Hospital, Baltimore, Md.

Levy, Lewis L., M.D., Neurology. Chief, Neurology Section, Veterans Administration Hospital, West Haven, Conn.

Lewis, Harvey H., M.D., Biology. Medical Corp, U. S. Air Force, New York, N. Y.

Lewis, John Sidney, M.D., Cancer. Staff, James Ewing Hospital, New York, N. Y.

Lewis, Louis W., M.D., Anesthesiology. Assistant Professor, University of Michigan, Ann Arbor, Mich.

Lieberman, Samuel L., M.D., Anesthesiology. Private Practice, Buffalo, N. Y.

Light, Frederick W., Jr., Ph.D., Medicine. Chief, Wound Assessment Branch, CWL, Army Chemical Center, Md.

Lindo, Clinton L., M.D., Medicine. Private Practice, Chicago, Ill.

Long, Edwin Tutt, M.D., Thoracic Surgery. Instructor, Surgery, University of Chicago, Chicago, Ill.

Louckes, Hortense, Ph.D., Physiology. Assistant Professor, Physiology, University of Tennessee, Memphis, Tenn.

Lucas, William G., M.D., Neuroanatomy. Resident Fellow, Neurology, University of Minnesota, Minneapolis, Minn.

Luft, John H., M.D., Anatomy. Research Fellow, Harvard Medical School, Boston, Mass.

Lustgarten, Bennett P., M.D., Hematology. Resident, Hematology, Mt. Sinai Hospital, New York, N. Y.

Lutz, W. Beale, M.D., Medicine. Assistant Resident, The Johns Hopkins Hospital, Baltimore, Md.

Lynn, Curt L., M.D., Psychology. Assistant Clinical Director, Marlboro State Hospital, Marlboro, N. J.

Lynner, R. E., M.D., Medicine. Resident, Department of Medicine, Akron City Hospital, Akron, Ohio.

McCullough, Clarence Joseph, M.D., Biology. Private Practice, Washington, Pa.

McManus, Ivy Rosabelle, Ph.D., Biochemistry. Assistant Professor, Yale University, New Haven, Conn.

McNeil, Neil Francis, M.D., Neurophysiology. Private Practice, Los Angeles, Calif.

Magee, Joseph Humphries, M.D., Internal Medicine. Private Practice, Lexington, Va.

Mandel, Emanuel E., M.D., Internal Medicine. Associate Professor, Medicine, Chicago Medical School, Chicago, Ill.

Morgan, Mary C., M.D., Radioisotopes. Associate Director, Radioisotope Unit, Veterans Administration Hospital, Houston, Texas.

Morris, John T., M.D., Biology. Chief, Medicine, Cullman Hospital, Cullman, Ala.

Mosca, Joseph C., M.D., Cancer. Private Practice, New York, N. Y.

Moss, N. Henry, M.D., Cancer. Instructor, Surgery, University of Pennsylvania, Philadelphia, Pa.

Murawski, Thaddeus J., M.D., Medicine. Staff, Glenridge Sanatorium, Schenectady, N. Y.

Murphy, Timothy R., M.D., Internal Medicine. Clinical Professor, Marquette Medical School, Marquette, Wis.

Naeslund, John, M.D., Gynecology. Professor, University of Upsala, Upsala, Sweden.

Neighbor, Gaylord, P., M.D., Internal Medicine. Private Practice, Kansas City, Kans.

Newcomer, Victor D., M.D., Dermatology. Associate Professor, Medicine, University of California, Los Angeles, Calif.

Pandazi, Andrew A., Ph.D., Shock Treatment. Instructor, Marquette University, Marquette, Wis.

Perloff, Phillip, M.D., Internal Medicine. Private Practice, San Francisco, Calif.

Peterson, Oliver H., Ph.D., Bacteriology. Head, Department of Bacteriology, Dr. Salsbury's Laboratories, Charles City, Iowa.

Pinson, Thomas J., D.D.S., Oral Surgery. Interne, University Hospital, Ann Arbor, Mich.

Plotz, Ernst Jürgen, M.D., Endocrinology. Assistant Professor, University of Chicago, Chicago, Ill.

Ponseti, Ignacio V., M.D., Metabolism. Associate Professor, Orthopedic Surgery, Children's Hospital, Iowa City, Iowa.

Porter, Howard Richard, M.D., Internal Medicine. Resident Physician, Veterans Administration Hospital, Long Beach, Calif.

Porter, Paul B., Ph.D., Psychology. Associate Professor, University of Utah, Salt Lake City, Utah.

Rabe, Edward F., M.D., Biology. Director, Department of Pediatrics, Geisinger Memorial Hospital, Danville, Pa.

Rapport, Maurice M., Ph.D., Immunology. Head, Section of Immunology, Sloan-Kettering Institute, New York, N. Y.

Rasmussen, Theodore Brown, M.D., Neurology. Professor, Neurology, McGill University, Montreal, P.Q., Canada.

Ray, William A., B.A., Physics. President & Chief Engineer, General Controls Co., Glendale, Calif.

Reddix, Merlin L., M.D., Internal Medicine. Private Practice, Shreveport, La.

Rietman, H. Jerome, M.D., Psychology. Resident Psychiatrist, Institute of Living, Hartford, Conn.

Rinkel, Herbert John, M.D., Biology. Private Practice, Kansas City, Mo.

Roberts, Eugene, Ph.D., Biochemistry. Chairman, Department of Biochemistry, City of Hope Medical Center, Duarte, Calif.

Rodman, Morton J., Ph.D., Pharmacology. Associate Professor, Pharmacology, Rutgers University, Newark, N. J.

Romano, Francisco Javier, M.D., Cardiology. Chief, Cardiology Section, Hospital Italiano, Buenos Aires, Argentina.

Rosenstein, Robert, B.S., Pharmacology. Teaching Assistant, Columbia University, New York, N. Y.

Saslaw, Samuel, M.D., Infectious Diseases. Associate Professor, Medicine, University Hospital, Columbus, Ohio.

Schoenlein, Henry W., M.S., Microorganisms. Director, Bacteriological Laboratories, Difco Laboratories, Inc., Detroit, Mich.

Stall, Bernard G. III, M.D., Cell Membranes. Assistant Professor, Medicine, University of North Carolina, Chapel Hill, N. C.

Stanger, Paul, A.B., Medicine. Student, Alfred University, Alfred, N. Y.

Steiner, George, B.A., Medicine. Medical Student, University of British Columbia, Vancouver, B.C., Canada.

Stoelting, Thomas, Ph.D., Geophysics. Chief Engineer, Empire Exploration Ltd, Inc., Salmon, Idaho.

Swann, Reginald L., M.A., Psychology. Associate Professor, Psychology, Teachers College of Connecticut, New Britain, Conn.

Talmers, Frederick N., M.D., Internal Medicine. Instructor, Medicine, Wayne University, Detroit, Mich.

Teichner, Warren H., Ph.D., Experimental Psychology. Chief, Psychology Branch, EPRO, QM Research & Development Center, Natick, Mass.

Waitzman, Morton B., Ph.D., Physiology. Research Associate, Western Reserve University, Cleveland, Ohio.

Wallbank, Alfred M., M.S., Microbiology. Student, East Lansing, Mich.

Walsh, Faith C., M.D., Neurology. Private Practice, Morristown, N. J.

Weiner, Lawrence M., Ph.D., Microbiology. Assistant Professor, Microbiology, Wayne University, Detroit, Mich.

Zahalsky, Arthur Clifford, M.A., Cellular Physiology. Instructor, School of Aviation Medicine, Gunter AFB, Ala.

STUDENT MEMBERSHIP

Reimer, Stanley M., B.S., Biochemistry. Graduate Student, Rutgers University, New Brunswick, N. J.

Spector, Abraham, A.B., Chemistry. Student, New York University, New York, N.Y.